☆ Mrs J H. Schaefer.

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ELECTRIC POWER STATIONS
ELECTRIC-RAILWAY SYSTEMS
LINE AND TRACK
LINE CALCULATIONS
MOTORS AND CONTROLLERS
ELECTRIC-CAR EQUIPMENT
MULTIPLE-UNIT SYSTEMS

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62

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# PREFACE

The International Library of Technology is the outgrowth of a large and increasing demand that has arisen for the Reference Libraries of the International Correspondence Schools on the part of those who are not students of the Schools. As the volumes composing this Library are all printed from the same plates used in printing the Reference Libraries above mentioned, a few words are necessary regarding the scope and purpose of the instruction imparted to the students of—and the class of students taught by—these Schools, in order to afford a clear understanding of their salient and unique features.

The only requirement for admission to any of the courses offered by the International Correspondence Schools, is that the applicant shall be able to read the English language and to write it sufficiently well to make his written answers to the questions asked him intelligible. Each course is complete in itself, and no textbooks are required other than those prepared by the Schools for the particular course selected. The students themselves are from every class, trade, and profession and from every country; they are, almost without exception, busily engaged in some vocation, and can spare but little time for study, and that usually outside of their regular working hours. The information desired is such as can be immediately applied in practice, so that the student may be enabled to exchange his present vocation for a more congenial one, or to rise to a higher level in the one he now pursues. Furthermore, he wishes to obtain a good working knowledge of the subjects treated in the shortest time and in the most direct manner possible.

In meeting these requirements, we have produced a set of books that in many respects, and particularly in the general plan followed, are absolutely unique. In the majority of subjects treated the knowledge of mathematics required is limited to the simplest principles of arithmetic and mensuration, and in no case is any greater knowledge of mathematics needed than the simplest elementary principles of algebra, geometry, and trigonometry, with a thorough, practical acquaintance with the use of the logarithmic table. To effect this result, derivations of rules and formulas are omitted, but thorough and complete instructions are given regarding how, when, and under what circumstances any particular rule, formula, or process should be applied; and whenever possible one or more examples, such as would be likely to arise in actual practice—together with their solutions—are given to illustrate and explain its application.

In preparing these textbooks, it has been our constant endeavor to view the matter from the student's standpoint, and to try and anticipate everything that would cause him trouble. The utmost pains have been taken to avoid and correct any and all ambiguous expressions—both those due to faulty rhetoric and those due to insufficiency of statement or explanation. As the best way to make a statement, explanation, or description clear, is to give a picture or a diagram in connection with it, illustrations have been used almost without limit. The illustrations have in all cases been adapted to the requirements of the text, and projections and sections or outline, partially shaded, or full-shaded perspectives, have been used, according to which will best produce the desired results. Half-tones have been used rather sparingly, except in those cases where the general effect is desired rather than the actual details.

It is obvious that books prepared along the lines mentioned must not only be clear and concise beyond anything heretofore attempted, but they must also possess unequaled value for reference purposes. They not only give the maximum of information in a minimum space, but this information is so ingeniously arranged and correlated, and the

indexes are so full and complete, that it can at once be made available to the reader. The numerous examples and explanatory remarks, together with the absence of long demonstrations and abstruse mathematical calculations, are of great assistance in helping one to select the proper formula, method, or process and in teaching him how and when it should be used.

A novel feature of this volume is four valuable sections on the design of electric power stations. Great care was taken in their preparation to make them thorough in every respect. Information pertaining to this subject was, heretofore, much scattered, so that this systematic and comprehensive treatise is of the greatest value to the designing, constructing, and operating engineer. The sections cover the design of both steam- and water-power stations. The portions relating to economy of maintenance are of special value to the operating engineer. At the present time, electric railroading is one of the most important branches of electrical engineering. The instruction in this branch has been made exceptionally thorough. There is no general textbook on this subject that at all compares with the subject matter given in this volume, which embraces discussions of the various railway systems, line and track construction and calculation, and a most detailed treatment of the apparatus used on single electric cars, as well as on multiple-unit trains. Elaborate colored car-wiring diagrams are provided.

The method of numbering the pages, cuts, articles, etc. is such that each subject or part, when the subject is divided into two or more parts, is complete in itself; hence, in order to make the index intelligible, it was necessary to give each subject or part a number. This number is placed at the top of each page, on the headline, opposite the page number; and to distinguish it from the page number it is preceded by the printer's section mark (§). Consequently, a reference such as § 16, page 26, will be readily found by looking along the inside edges of the headlines until § 16 is found, and then through § 16 until page 26 is found.

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# ELECTRIC POWER STATIONS

(PART 1)

## INTRODUCTION

**1.** In addition to the study of the various systems of electrical distribution and the types of dynamos and auxiliary electrical apparatus required in the power station for carrying out the distribution, it is necessary to consider the various appliances, used in the power station, which are not electrical in character and also to take up the power station as a whole. The first involves a study of those types of steam boilers, steam engines, waterwheels, etc. that are best adapted for the purpose. It also includes a consideration of the features that govern the location of the plant, type of building, fuel, water supply, etc.

**2.** The electric power station of the present day being built for generating electricity as a commercial product, follows in the legitimate line of its predecessors and contemporaries, the waterworks and the gasworks. In each is concentrated the apparatus necessary to manufacture or force through circulating or distributing mediums its particular product for the supply of individual consumers in quantities as required.

The electric power station involves the assembling within a properly designed building, situated in a suitable location, such a combination of selected apparatus as will facilitate the extracting of the heat units contained in the fuel, and their transmission over a given territory; or, if a water power station, the conversion of the foot-pounds of energy developed by the falling water, into electric energy for similar distribution.

Of the original energy contained in the fuel, if coal is used, it is surprising how much is lost in conversion and transmission; this is demonstrated under the heading Efficiency of Power Stations. These enormous losses serve to emphasize the importance of the most judicious selection of every appliance requisite for an electric power station, to the end that the loss may be reduced to a minimum.

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## LOCATION

**3.** The standard of excellence for the location of the station will be described with a view to attaining it as far as practicable, when property is about to be selected. The most desirable plot will meet the following conditions:

(*a*) The ground should have a suitable elevation above high-water mark to avoid danger from floods, it should be nearly level, and should have ample area for construction of the contemplated station and its future growth to more than four times its immediate estimated capacity. There should also be an abundance of space for a storage warehouse that will contain all supplies, and yard room for poles, crossarms, underground materials, coal, teams, etc.; in fact, a plot of ground amply large for the entire future business of the company. Any subdivision of working force, either in actual station operation, supply department, or offices, means an added future expense of supervision over what would be the minimum cost in the ideal location.

(*b*) The selection of a location for building a power station involves a careful analysis of its environment, because there are several points which, if not given due attention, may be the cause of an avoidable expense of greater or less amount, either in cost of construction, maintenance, operation, or future legal entanglements.

(*c*) The ideal site will not involve any annoyance to the surrounding neighborhood, due to the noise of machinery in operation, the delivery of coal, the handling of ashes, smoke, dust, smell of oil, and the other numerous unavoidable incidents that continually attend on central-station operations

and are objectionable when near districts containing schools, churches, residences, or similar buildings.

(*d*) The fire-risk must be considered by careful investigation of all the surroundings with a view to danger from external fire. A power station is liable to as great danger from fire in adjacent buildings as within its own walls.

(*e*) The least cost of construction will be obtained on a site where excavations are readily made at minimum cost, where extra piling and blasting are not necessary, where firm hard pan, clay, gravel, or rock are found within a few feet of the surface, and where no more grading is required than the usual filling in and grading off around foundations. The security of the structure depends on solid underlying soil or rock on which may be built foundations of unquestionable solidity. Piling on soft ground is expensive, and causes more or less anxiety about the security of the structures.

(*f*) There should be an abundant, never-failing supply of pure water for boiler-feed purposes, and, if possible, for condensing purposes also, free of cost except for piping; therefore, a waterside location is preferable, and the elevation for pumping should not exceed 18 feet. A variation from this will add to what will be normal cost for these items under ideal conditions. If a condensing station is desired, the free supply of water for this purpose is essential even if water for boiler feed must be purchased.

(*g*) The fuel supply should be absolutely reliable and delivered at the premises by railroad on elevated trestle, or boat alongside, at the lowest rates. The storage bunker should be of such capacity as to permit securing a full stock during the season of lowest prices, and sufficient for 4-months' use to carry the winter load, or over any long strike at coal mines or on transportation lines, and the arrangement should be such that inclement weather may not, at any season, delay delivery and thereby imperil station operation. If oil is used for fuel, the storage tanks should be of ample capacity, located in vaults below ground, and properly ventilated.

(*h*) The electrical center of the entire district to which

power is supplied is the most desirable location for the station, other things being equal, so that the normal cost of copper for feeders may not be exceeded, and the whole cost of the system of distribution kept within the lowest limits. The relative advantage of different sites as regards cost of copper can readily be ascertained by estimating, for the maximum load, the pounds of copper under a given loss from several locations, and comparing costs.

Ideal locations possessing every requisite are not always secured, but each variation therefrom should receive its estimate of cost. The value of one location should be compared with another on the cost of the several items of construction and operation, and thus an intelligent conclusion can be reached. Extra cost of operation at one location over another should be capitalized on a 6-per-cent. basis to show the relative values. That is, if one location represented an additional yearly cost of operation of $300 over some other location, the first location should be charged with an additional investment of $5,000 capital in order to make a fair comparison of the first cost in the two cases.

**4. Reliability.**—An electric power station is constructed to supply its product on instantaneous demand and in any amount irrespective of other notice from the consumers to the producer. The consumers make a contract for electrical energy, and an abundant supply sufficient for their requirements must be available on demand, the same as water or gas. Therefore, special stress must be laid on the point of insuring absolute reliability of service throughout every detail of the whole equipment and system of distribution. No station can be considered a reliable source of supply unless every feature of its equipment liable to derangement or accident is at least duplicated, and so interconnected throughout that in the event of trouble the load may be transferred from one set of apparatus to another, without causing the slightest inconvenience to consumers, or interfering with the continuity of the service. If the service from the station is irregular or subject to interruption, this quickly

creates in the minds of the consumers a lack of confidence in the ability of the company to fulfil its obligations in supplying its product, and such lack of confidence on the part of the public will be a serious impediment to the growth of the business. For these reasons the duplication of apparatus, and the complete interchangeability of connections should always be insisted on as of first importance.

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## EFFICIENCY OF POWER STATIONS

**5.** In an electric power station it is important to know as accurately as possible, what degree of economy is obtained from the entire equipment operated as a unit; or, taking the total energy supplied in the form of heat units held in the fuel, what percentage is lost and what percentage is recovered in the form of useful work in light or power. The commercial success or failure of an electric power station is largely determined by the efficiency and reliability of the equipment, and the actual efficiency is therefore a subject of special interest to the central-station manager and the engineer.

**6.** The **efficiency** of the entire plant in the aggregate must necessarily depend on the net efficiency of each unit of apparatus composing the equipment, since their accumulative losses account for a large part of the total energy wasted in the system, thus readily affecting the final efficiency. Emphasis is given to these facts to the end that, knowing of certain fixed and irreparable losses, one may fully realize the importance of using such equipment as will keep these losses down to the minimum. In the electric power station operated by steam the heat units in the fuel represent the original amount of energy applied, and which are generally accepted as 14,600 British thermal units per pound of coal, it being understood that much coal averages less than this, and an excess is exceptional. The efficiency of fuel may be stated as the total amount of heat it is capable of generating. The proportion of the generated heat that may be utilized, depends

on the efficiency of the boiler. The efficiency of a coal depends not only on its chemical composition and theoretical value in heat units contained per pound, but also on the percentage of moisture, ash, and non-combustible material contained, as well as its size and condition for use. In the burning of coal there are certain unavoidable losses (such as heat lost in moisture, heat lost in excess of air supplied, heat lost in products of combustion, heat lost in unburnt coal), the aggregate of which will rarely fall short of 15 per cent., and more frequently exceed that amount.

**7. Boiler Efficiency.**—The efficiency of a boiler may be defined as the ratio of the heat utilized in evaporating the water to the total heat supplied by the combustion of the fuel. It will vary according to the relative ratios of heating surface to grate area, the cleanliness of the boiler, method of setting, thickness of plates, etc. Exhaustive tests show that **boiler efficiency** is sometimes as low as 21 per cent., and seldom reaches 88 per cent.; with the best types of boilers, with grate area and heating surface carefully proportioned, an efficiency of 75 to 80 per cent. is attainable with a clean boiler very carefully managed. There is such a great difference between a competent and an incompetent fireman that the efficiency of the best-designed boiler under the most favorable conditions may be greatly reduced by bad management.

**8. Engine Efficiency.**—The best engine, apart from its boiler, has about five-sixths the efficiency of a perfect engine, the other sixth being lost through waste of heat by radiation, conduction, cylinder condensation, and friction. Its efficiency as a heat engine is from 10 to 15 per cent.; that is, of the energy represented by the heat stored in the steam, only from 10 to 15 per cent. is converted into useful work. Engine friction is a factor of waste in all engines, and the size, type, and condition of the engine will affect the resistance and the effort necessary to overcome it. This will vary from 1 pound per square inch of piston, in large, well-designed engines, to 3 or 4 pounds in inefficient

machines. The net useful work is represented by the indicated work minus the engine friction, and in good practice this will be 85 to 90 per cent., which represents the mechanical efficiency as a machine. That is, of the actual amount of indicated work done in moving the piston in the cylinder, 85 to 90 per cent. is available at the engine shaft, the balance being lost in friction between the various rubbing surfaces.

Of the boiler and engine combined, Dr. R. H. Thurston states "that of all the heat derived from the fuel, about seven-tenths is lost through the existence of natural conditions over which man can probably never expect to obtain control, two-tenths are lost through imperfections in apparatus, and only one-tenth is utilized in good engines." In this combination of waste probably two-tenths at least of the heat derived from the fuel is lost in the boiler and steam pipes.

**9. Generator Efficiency.**—In electric generators ranging in output from 50 to 1,000 kilowatts the efficiency at full load will range from 90 to 94 per cent.; with half load, somewhat less. In this statement no distinction is made between direct-current and alternating-current generators. Outside of the generator, other sources of loss are found; in electrical conductors and connections, and at any point where an abnormal rise of temperature can be detected, it may be certain that a loss is occurring.

**10. Switchboard losses** may reach from .125 per cent. upwards, and may be prevented by exercising great care in the selection of switches, instruments, etc., and particularly in details of bus-bar work and connections. All bus-bars and electrical conductors and connections must be liberal in capacity; every joint should have true surfaced contacts of at least twice the area of the conductor, and all bolting, soldering, or brazing must be very carefully done.

**11. Outside Losses.**—Losses outside of the station will largely depend on the characteristics of current and system. The actual loss in distributing conductors can be accurately predetermined for specified loads. With the direct-current system the maximum loss will take place during the hours of

maximum load, and the loss is reduced as the load goes off; with the alternating-current system, the line loss is comparatively small, but there is considerable loss in the transformers even when the useful load is very light. The magnetizing current of the transformers causes a certain amount of copper loss and the core losses are practically constant at all loads.

**12. Selecting Station Equipment.**—Economy consists in avoiding all unnecessary expenditures and losses, and in making a profitable disposition of what would otherwise be wasted. In aiming for economy of fuel the whole combination of boilers, engines, condensers, piping, pumps, heaters, etc. must be considered individually and collectively. A poor boiler will not demonstrate the virtues of a good engine, and likewise an engine extravagant in steam may render useless all the economy obtained with a good boiler. The contract requirements for a boiler, engine, generator, or any piece of apparatus should be based on the highest economies demonstrated in its class; these should be clearly set forth in the contract and specifications, and should be rigidly adhered to. The impossible should not be demanded. The man who designs and erects a station should set aside all personal preferences and prejudices, and should be broad enough to select his equipment on established merit only. If an article secured from a manufacturer of doubtful reputation is found unsatisfactory after it is delivered, erected, and started, the purchasing company will have no satisfactory redress. The removal and replacement by some other apparatus may make good the deficiency, but can never compensate for the annoyance, loss of time, and money involved.

## LOAD CURVES

**13. Determination of Probable Load.**—In advance of building a station it is possible to construct a load diagram that will closely represent the load curve or daily output of the station, from the following data: First, a careful canvass of the lighting and power to be obtained within the area of the district to be supplied. Second, the subdivision of each

kind of service under different classifications, such as motive power, street lighting, store lighting, hotel lighting, residence lighting, theater lighting, church lighting, etc., and an estimate of the percentage of connected load that will be operated during certain hours, and for a given period.

The combination of these several classified loads will overlap at certain periods, and unite to form the load line of the station. The load line will vary during the different seasons of the year, and under normal conditions the maximum load will be met from December 1 to January 1 in cities and towns. In summer resorts, the maximum load is at the height of business during the summer season. The station must always be prepared to take care of this maximum load, and to be so equipped frequently requires investment in expensive apparatus that has an earning capacity during three winter months only and must lie idle for the remainder of the year. For this reason the apparatus so employed does not require to be of so costly or economical a character as that used daily during the entire year.

**14. Example of Load Diagram.**—The load diagram shown in Fig. 1 combines arc lighting, incandescent lighting, and motive power supplied from a single station. The arc-lighting load represented by the full line is all-night lighting, starting at 6 P. M. and carrying the total load until 5 A. M. The load for arc lighting is represented at 75 kilowatts for 100 burning lights. The output for incandescent lighting is indicated by the dash line and represents a combination of lighting in private residences, stores, saloons, hotels, theaters, etc. It will be noted that the load is least between 11 P. M. and 5 A. M. There is a slight peak at 6 A. M. which again diminishes, and as business lighting starts up in the various establishments, the load increases. Assuming that the day is a stormy one, there is a gradual increase of load until the peak is reached at 6 P. M., after which many stores and places of business close up. There is an increase again after 6 P. M. on account of additional lighting used in theaters and places of amusement. The lighting on the incandescent

system gradually diminishes until midnight. The motive-power load is represented by the dotted line, which shows the aggregate of current required by motors used for manufacturing purposes, elevators, etc. This load is almost constant between 7 A. M. and 12 o'clock noon, at which time a number of motors in manufacturing establishments are shut off; these are started again at 1 P. M. and gradually closed off between 5 and 6 P. M. The total load on the station, which is a combination of all of the above, is represented by the dot-and-dash line and shows the demands on

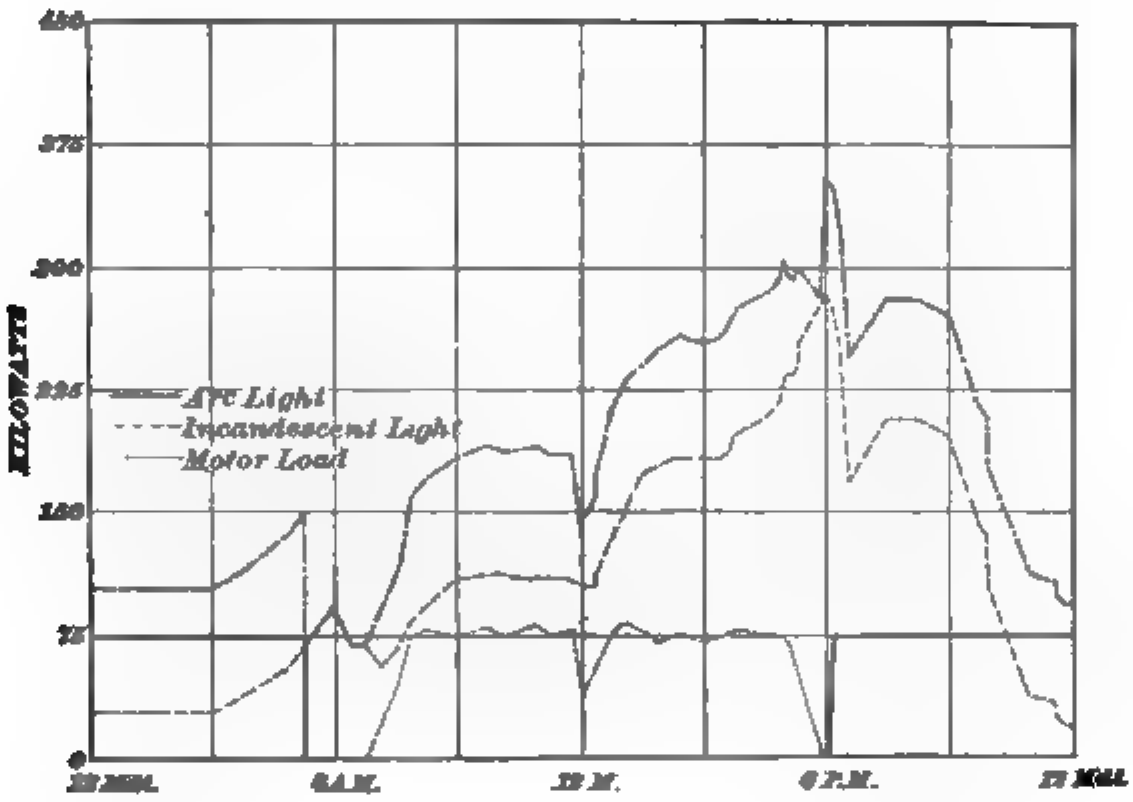


FIG. 1

the station by the combination of the various kinds of service supplied. This line is found by adding the ordinates of the three lines representing the various loads. If it is assumed that the arc lighting is supplied from the alternating-current system, the motive power from the direct-current system, the incandescent lighting in the business district and part of the residence lighting from the direct-current, and the remainder of the incandescent lighting in outlying districts from the alternating current, it becomes evident that a

station supplying current for this variety of business can conveniently do so by the use of double-current generators, the arc lighting and alternating-current incandescent lighting being served from the alternating side of the generator, and the motive power and business district lighting from the direct-current side.

**15.** If this station were equipped with two double-current generators each of 100 kilowatts and one double-current generator of 300 kilowatts, it would have such a combination of apparatus as could be economically manipulated for the daily load during week days. On Sunday, the incandescent load and motive load is expected to be at the lowest point between 6 A. M. and 6 P. M.; therefore, during these hours on Sunday, which would represent 624 hours per year, the load could be carried on a single 100-kilowatt generator running at about one-half load. This illustrates a typical case, and in such a station provision should be made for an early increase in the number of generating units.

**16. Provision for Future Extensions.**—It is a matter of history, that during the past 15 years, 90 per cent. of the stations have been designed on too small a scale to meet successfully and economically the rapid growth and expansion of the business; constant extension, moving, and rebuilding is evidence of the enormous cost entailed by this lack of foresight. For these reasons the plant should be such as to admit readily of extensive additions, and the future should be anticipated to such a large degree that changes and improvements necessary to accommodate an enlarged equipment can be readily and economically harmonized with the original design without destroying first construction or causing expensive alterations.

## STORAGE OF COAL

**17.** It is very important that every electric power station using coal should be provided with a large storage capacity to insure a continuous supply of fuel during extended periods of bad weather, delays in transportation, strikes, etc., and also to permit taking advantage of low market rates. Coal-storage bunkers should be so arranged as to admit of the most economical methods for handling the coal, and a thoroughly reliable system of conveyers should be installed when the plant is sufficiently large to warrant the expense.

In designing a coal bunker, no fixed rule can be given as to its dimensions, except to make it as large as possible according to the space available. The approximate weights of coal per cubic foot are as follows:

| | | |
|---|---|---|
| Anthracite | Buckwheat . . . . | 55 pounds per cubic foot |
| | Pea . . . . . . . . . | 50 pounds per cubic foot |
| | Broken . . . . . . | 60 pounds per cubic foot |
| Bituminous . . . . . . . . . | | 45 to 50 pounds per cubic foot |

**18. Pressure Exerted by Coal.**—If bituminous coal is piled up, it will assume a slope of about 35°, or in other words, its angle of repose is 35°. With anthracite coal, the angle of repose is about 27°. For example, in Fig. 2, if $ab$ represents a retaining wall for holding back bituminous coal, the coal will, if simply piled up, assume the slope $am$. If the space is filled level with the top of the wall along the line $bm$, there will be a certain pressure exerted per each foot length of wall due to the mass of coal $abm$. If the coal is heaped up in the bunker until it assumes the slope $bc$, which is the maximum slope it can assume without running off, it is plain that the pressure exerted per lineal foot of the retaining wall will be considerably greater than that when the surface of the coal was level. Table I, prepared by the Link Belt Engineering Company, shows the pressure exerted

for each lineal foot of wall for walls of different heights, when the coal is filled level along the line *b m*, Fig. 2, and when it is piled up along the line *b c*. For example, if the depth of the wall *b a* were 10 feet and the coal filled flat with the top along the line *b m*, the total pressure exerted on a strip of the wall of height *b a* = 10 feet and breadth 1 foot will be 637 pounds. The table also gives the pressure on the lowest foot of wall, or in other words, the maximum pressure to which any square foot of wall is subjected; in this case the pressure on the lowest foot is 121 pounds. If the coal were piled along the line *b c*, the total pressure would have been 1,000 pounds per lineal foot and 190 pounds on the lowest foot.

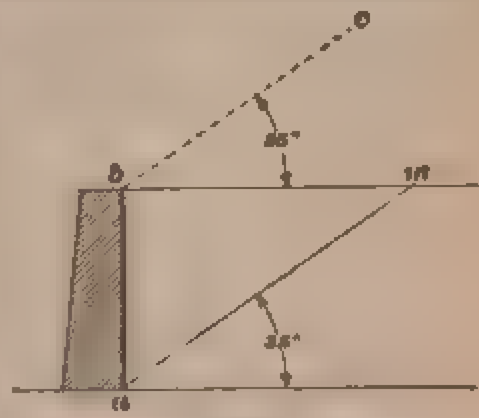

FIG. 2

Table II is similar to Table I, but shows the pressures exerted by anthracite when piled up to the line *b m*, Fig. 3, or heaped up to the slope *b c*. The pressures exerted by anthracite are fully 50 per cent. greater than those exerted by bituminous, partly because of the greater weight per cubic foot of the anthracite and partly because of its smaller angle of repose, which is shown in Fig. 3.

**19. Labor-Saving Appliances.**—In designing an electric power station and its equipment, especial attention should be given to the largest practicable reduction of labor throughout the station; convenience of arrangement, size of units, and many other features will, if rightly selected, accomplish this purpose. Appliances for handling coal and ashes have been brought to a high degree of perfection and are great labor savers. At a reasonable cost it is possible to arrange for automatically handling coal from the time it

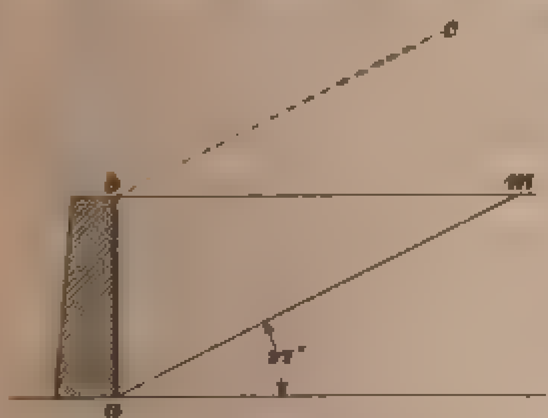

FIG. 3

## TABLE I

### HORIZONTAL PRESSURE EXERTED BY BITUMINOUS COAL AGAINST VERTICAL RETAINING WALLS PER FOOT OF LENGTH

*Link Belt Engineering Company*

| Depth *b a* in Feet | Horizontal Surface *b m* | | Sloping Surface *b c* | | Depth *b a* in Feet | Horizontal Surface *b m* | | Sloping Surface *b c* | |
|---|---|---|---|---|---|---|---|---|---|
| | Total Pressure Pounds | Pressure on Lowest Foot Pounds | Total Pressure Pounds | Pressure on Lowest Foot Pounds | | Total Pressure Pounds | Pressure on Lowest Foot Pounds | Total Pressure Pounds | Pressure on Lowest Foot Pounds |
| 1 | 6.4 | 6.4 | 10 | 10 | 26 | 4,305 | 325 | 6,760 | 510 |
| 2 | 25. | 19. | 40 | 30 | 27 | 4,641 | 338 | 7,290 | 530 |
| 3 | 57. | 32. | 90 | 50 | 28 | 4,993 | 350 | 7,840 | 550 |
| 4 | 102. | 45. | 160 | 70 | 29 | 5,358 | 363 | 8,410 | 570 |
| 5 | 159. | 57. | 250 | 90 | 30 | 5,732 | 376 | 9,000 | 590 |
| 6 | 229. | 70. | 360 | 110 | 31 | 6,122 | 389 | 9,610 | 610 |
| 7 | 312. | 83. | 490 | 130 | 32 | 6,523 | 401 | 10,240 | 630 |
| 8 | 407. | 96. | 640 | 150 | 33 | 6,935 | 414 | 10,890 | 650 |
| 9 | 516. | 108. | 810 | 170 | 34 | 7,362 | 427 | 11,560 | 670 |
| 10 | 637. | 121. | 1,000 | 190 | 35 | 7,778 | 440 | 12,250 | 690 |
| 11 | 770. | 134. | 1,210 | 210 | 36 | 8,253 | 452 | 12,960 | 710 |
| 12 | 917. | 146. | 1,440 | 230 | 37 | 8,754 | 465 | 13,690 | 730 |
| 13 | 1,076. | 159. | 1,690 | 250 | 38 | 9,193 | 478 | 14,440 | 750 |
| 14 | 1,248. | 172. | 1,960 | 270 | 39 | 9,682 | 490 | 15,210 | 770 |
| 15 | 1,433. | 185. | 2,250 | 290 | 40 | 10,192 | 503 | 16,000 | 790 |
| 16 | 1,630. | 197. | 2,560 | 310 | 41 | 10,669 | 516 | 16,810 | 810 |
| 17 | 1,840. | 210. | 2,890 | 330 | 42 | 11,236 | 529 | 17,640 | 830 |
| 18 | 2,063. | 223. | 3,240 | 350 | 43 | 11,797 | 541 | 18,490 | 850 |
| 19 | 2,298. | 236. | 3,610 | 370 | 44 | 12,331 | 554 | 19,360 | 870 |
| 20 | 2,548. | 248. | 4,000 | 390 | 45 | 12,968 | 567 | 20,250 | 890 |
| 21 | 2,809. | 261. | 4,410 | 410 | 46 | 13,478 | 580 | 21,160 | 910 |
| 22 | 3,083. | 274. | 4,840 | 430 | 47 | 14,100 | 592 | 22,090 | 930 |
| 23 | 3,369. | 287. | 5,290 | 450 | 48 | 14,679 | 605 | 23,040 | 950 |
| 24 | 3,669. | 299. | 5,760 | 470 | 49 | 15,275 | 618 | 24,010 | 970 |
| 25 | 3,981. | 312. | 6,250 | 490 | 50 | 15,925 | 631 | 25,000 | 990 |

## TABLE II

### HORIZONTAL PRESSURE EXERTED BY ANTHRACITE COAL AGAINST VERTICAL RETAINING WALLS PER FOOT OF LENGTH

*Link Belt Engineering Company*

| Depth *b a* in Feet | Horizontal Surface *b m* | | Sloping Surface *b c* | | Depth *b a* in Feet | Horizontal Surface *b m* | | Sloping Surface *b c* | |
|---|---|---|---|---|---|---|---|---|---|
| | Total Pressure Pounds | Pressure on Lowest Foot Pounds | Total Pressure Pounds | Pressure on Lowest Foot Pounds | | Total Pressure Pounds | Pressure on Lowest Foot Pounds | Total Pressure Pounds | Pressure on Lowest Foot Pounds |
| 1 | 9.78 | 9.78 | 14.2 | 14.22 | 26 | 6,611.1 | 498.78 | 9,612.8 | 725.21 |
| 2 | 39.12 | 29.34 | 56.9 | 42.66 | 27 | 7,129.5 | 518.35 | 10,366 | 753.67 |
| 3 | 88.02 | 48.90 | 127.1 | 71.10 | 28 | 7,667.6 | 537.90 | 11,140. | 782.10 |
| 4 | 156.48 | 68.46 | 227.5 | 99.54 | 29 | 8,225.0 | 557.46 | 11,988 | 810.54 |
| 5 | 244.50 | 88.02 | 355.5 | 127.98 | 30 | 8,802.0 | 577.01 | 12,797 | 839.0 |
| 6 | 352.08 | 107.58 | 511.9 | 156.42 | 31 | 9,398.5 | 596.59 | 13,665. | 867.41 |
| 7 | 479.22 | 127.14 | 696.8 | 184.86 | 32 | 10,015. | 616.14 | 14,561 | 895.86 |
| 8 | 625.92 | 146.70 | 910.1 | 213.30 | 33 | 10,650. | 635.70 | 15,486. | 924.30 |
| 9 | 792.18 | 166.26 | 1,151.8 | 241.74 | 34 | 11,306. | 655.26 | 16,439. | 952.7 |
| 10 | 978.00 | 185.82 | 1,422.0 | 270.18 | 35 | 11,980. | 674.81 | 17,420. | 981.19 |
| 11 | 1,183.38 | 205.38 | 1,720.6 | 298.62 | 36 | 12,675 | 694.30 | 18,429. | 1,009.6 |
| 12 | 1,408.32 | 224.94 | 2,047.7 | 327.06 | 37 | 13,389. | 713.94 | 19,467. | 1,038.1 |
| 13 | 1,652.82 | 244.50 | 2,403.2 | 355.50 | 38 | 14,123. | 733.50 | 20,533 | 1,066.5 |
| 14 | 1,916.88 | 264.06 | 2,787.1 | 383.94 | 39 | 14,875. | 753.07 | 21,629 | 1,095.0 |
| 15 | 2,200.50 | 283.62 | 3,199.5 | 412.38 | 40 | 15,648. | 772.63 | 22,752. | 1,123.4 |
| 16 | 2,503.68 | 303.18 | 3,640.3 | 440.82 | 41 | 16,440. | 792.20 | 23,904 | 1,151.8 |
| 17 | 2,826.42 | 322.74 | 4,109.6 | 469.26 | 42 | 17,252. | 811.74 | 25,084. | 1,180.3 |
| 18 | 3,168.72 | 342.30 | 4,607.3 | 497.70 | 43 | 18,083 | 830.73 | 26,293. | 1,208.7 |
| 19 | 3,530.58 | 361.86 | 5,133.4 | 526.14 | 44 | 18,934 | 850.86 | 27,530 | 1,237.2 |
| 20 | 3,912.00 | 381.42 | 5,688.0 | 554.58 | 45 | 19,804. | 870.41 | 28,793 | 1,265.6 |
| 21 | 4,313.00 | 400.98 | 6,271.0 | 583.26 | 46 | 20,695. | 889.99 | 30,090 | 1,294.0 |
| 22 | 4,733.5 | 420.54 | 6,882.5 | 611.46 | 47 | 21,605. | 909.54 | 31,412. | 1,322.3 |
| 23 | 5,173.7 | 440.10 | 7,522.5 | 639.90 | 48 | 22,533 | 929.10 | 32,763 | 1,350.9 |
| 24 | 5,633.3 | 459.67 | 8,190.7 | 668.35 | 49 | 23,482. | 948.66 | 34,143. | 1,379.4 |
| 25 | 6,112.6 | 479.22 | 8,887.5 | 696.79 | 50 | 24,450. | 968.21 | 35,550. | 1,407.9 |

reaches the station by car or boat, until the ashes are removed from the station. For example, the coal may be delivered by car or boat and rapidly transferred, by traveling conveyers, to an elevated coal bunker at a cost of from 3 to 6 cents per ton for power and attendance; it may be delivered direct from the coal bunker, through chutes, to each mechanical stoker, each chute being fitted with a recording apparatus for weighing the coal delivered to each hopper and stoker.

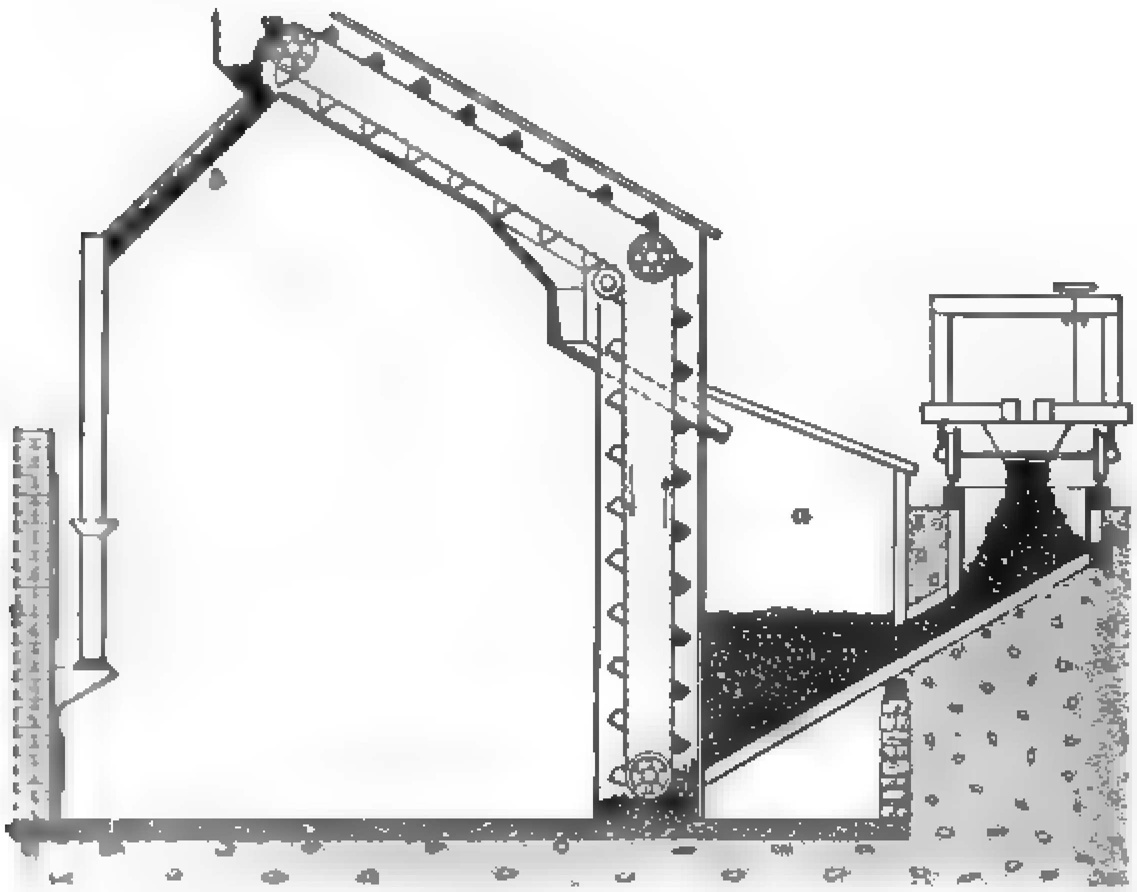


FIG. 4

**90.** Fig. 4 shows an efficient type of coal conveyer made by the Link Belt Engineering Company; it is of the continuous-running type and takes the coal from the storage bin *a* and delivers it to the reservoir chute *b* from which it goes to the hopper of the mechanical stoker, which feeds it automatically under the boiler. The conveyer consists of a number of buckets on an endless chain, the buckets filled with coal being shown black and the empty buckets white. It is usually driven by an electric motor or small steam engine.

**21.** Fig. 5 shows a coal-storage and conveying arrangement installed by the C. W. Hunt Company. The coal is here brought to the station in the barge *a* and is removed by the bucket *b*, which is drawn up the incline and discharged into the storage bin directly above the boilers *c*. The coal passes through the weighing device *g* to the chute *d* and is fed, by the automatic stoker, on to the inclined grate bars *e*. The ashes drop into a carrier at *f* and are conveyed to a

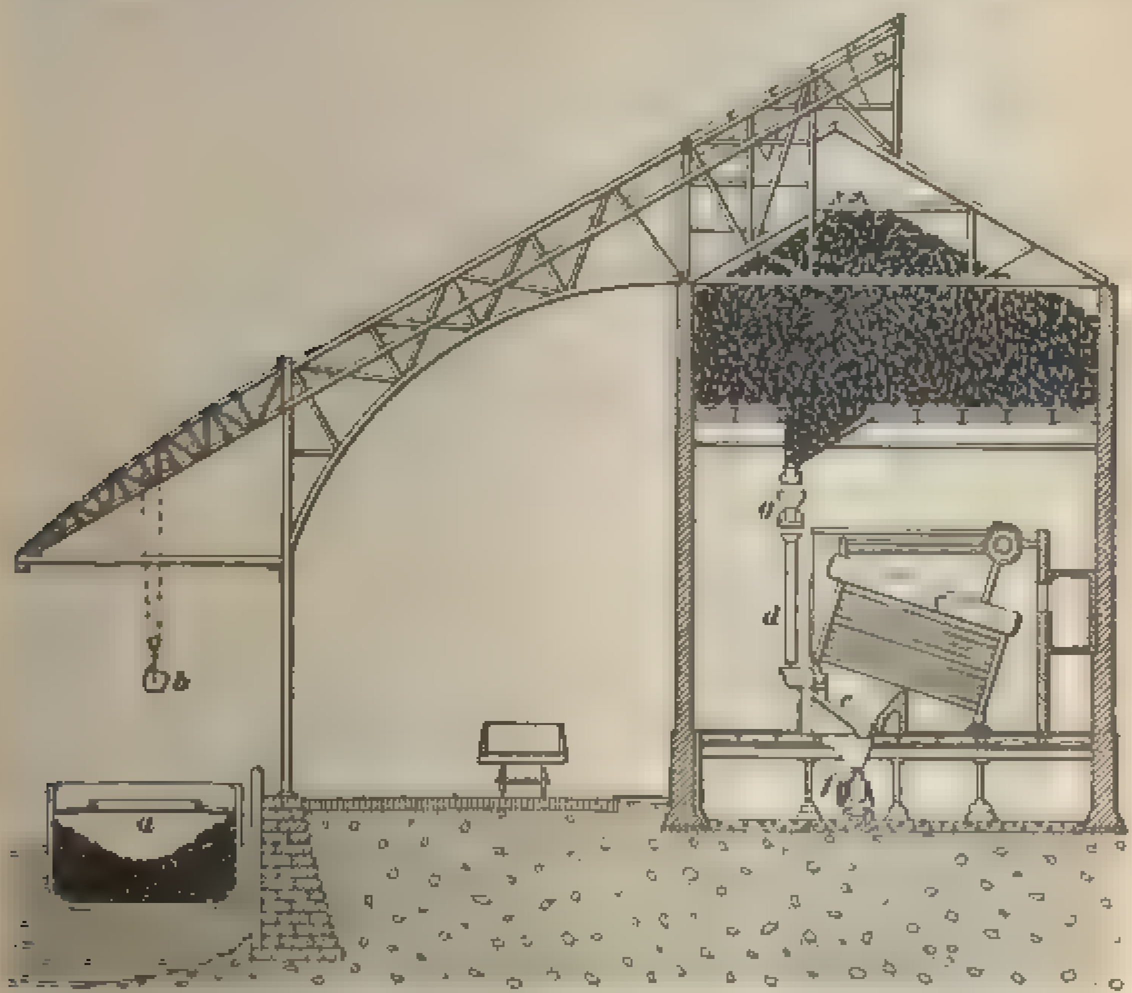


FIG. 5

hopper in the second story of the building, from which they are readily loaded into wagons for removal. No shoveling is required for handling either coal or ashes. Before passing into the spout *d*, the coal is run into the suspended hopper *g* where it is weighed, thus allowing an accurate record to be kept of the amount of coal burned under each boiler.

**22.** Fig. 6 shows an arrangement for a coal-storage plant, where the coal is delivered either by water or rail;

Fig. 6

the storage bin is capable of holding 1,000 tons. The coal, after being unloaded, is passed through crushers to reduce the large lumps to suitable size and is then carried by the conveyers to the storage bin. A horizontal conveyer that can be run in either direction passes across the top of the bin, as indicated at *a*; it takes the coal from either of the other conveyers and delivers it in any desired part of the storage bin, thus allowing the bin to be evenly filled. The coal is delivered from chutes arranged at the bottom of the bin. The operation of the other parts will be plain from Fig. 6, so that further comment is unnecessary. Fig. 7 gives the general appearance of the bin, showing the end where coal is unloaded from the cars. Fig. 8 shows the unloading of coal from barges for the same installation.

There are many kinds of coal conveyers in use, but it is impossible to mention more than a few typical examples here. One type that is largely used for station work is the belt

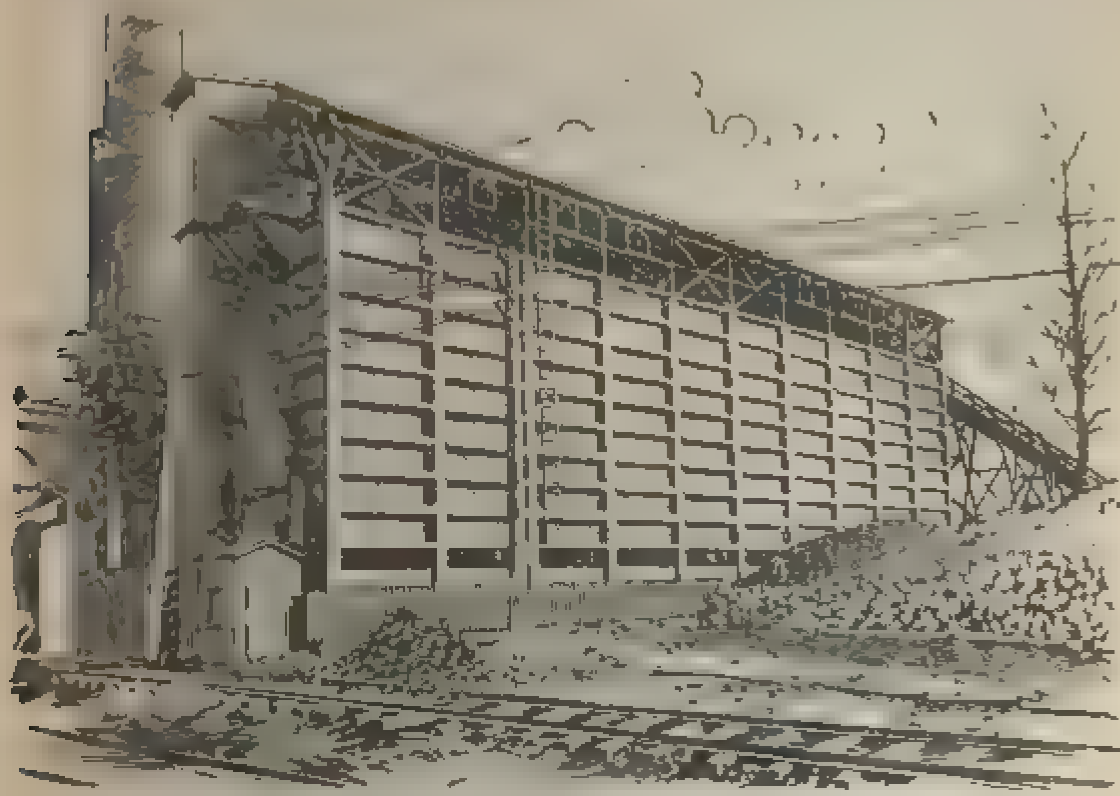

FIG. 7

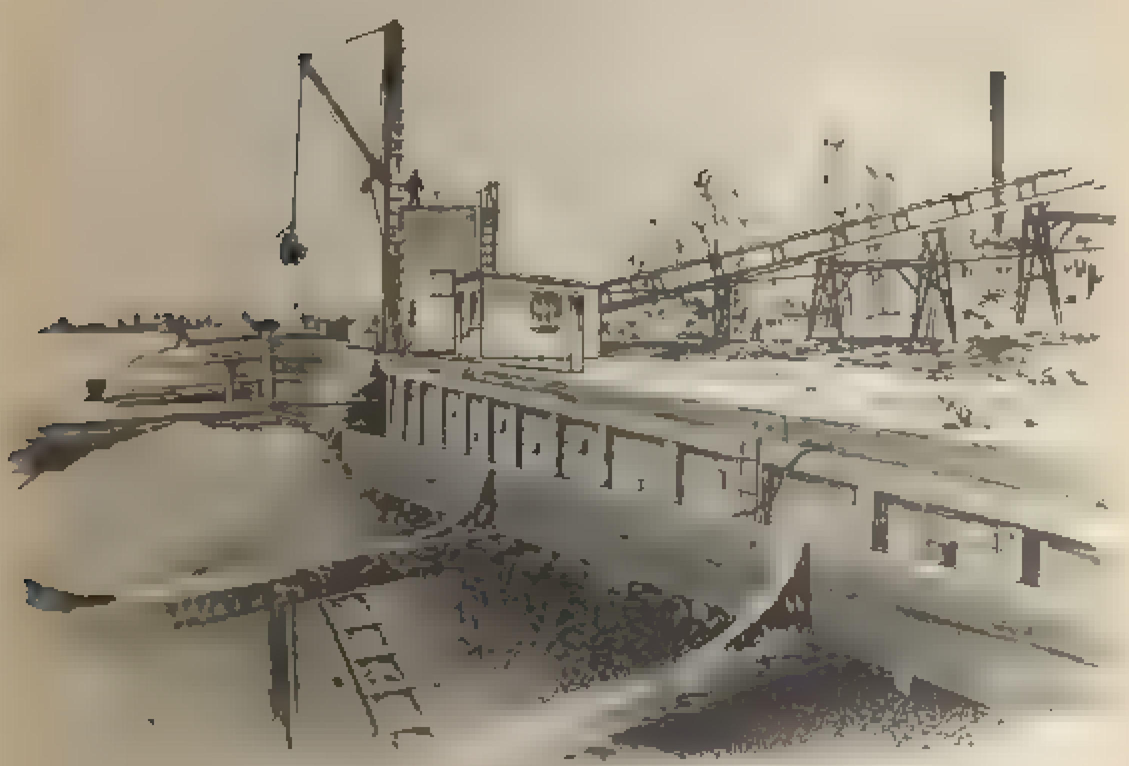

FIG. 8

conveyer, of which the Robins, Fig. 9, is a prominent example. This consists simply of a continuous rubber belt running up an incline, and resting on inclined rollers that make it assume a trough shape. The coal lies in the trough formed by the belt and is carried up the incline by the motion of the belt. Of course, the pitch of the incline has to be less than that which would cause the coal to slide on the belt.

FIG. 9

**23. Miscellaneous Devices.**—In addition to the labor-saving devices for handling coal and ashes, there are a number of appliances that, while not so important, effect a considerable saving and make the station much more convenient to operate. A traveling crane is a great convenience for lifting heavy parts quickly and will save in time and labor a large percentage of its cost, which will be from $600 up, according to the type and load capacity. Oil tanks, oil filters, oil piping and circulating pumps not only reduce

labor but increase the cleanliness, safety from fire, and effect an economy of from 25 to 40 per cent. in the amount of oil used. Recording meters should be used to record the current generated and supplied to each feeder, including that used for station supply; these meter readings assist in accuracy of records and aid in calculating station efficiency. Every department of the station service should be so systematized and its cost accounted for, that the total cost per kilowatt-hour can be accurately determined and the cost of each item reduced to a kilowatt-hour basis.

## FOUNDATIONS

**24.** That portion of a substructure that serves as a base on which to erect a superstructure, is designated as the **foundation.** Its object is to obtain a solid base on which to erect the machinery or building; the stability of the entire structure is threatened by a foundation of insufficient size, improperly built, or of unsuitable materials. Where supporting heavy machinery, the foundation should, without the slightest vibration, withstand the incessant daily shocks to which it will be subjected. The least yielding may cause fractures in walls or spring the frame of the machinery, causing destructive strains, heating of bearings, and loss of power by increased friction. Suitable foundations are therefore of first importance to the life and efficiency of whatever they support, and deserve the most careful consideration.

All foundations for moving machinery should be constructed absolutely independent of the walls of the building, but where two or more foundations for individual units are within a short distance of each other, it is better that they should be bonded together, and thus form a monolithic structure, as the combined mass and increased area will render them the more capable of withstanding greater strains than when individually constructed.

**25.** Prior to purchasing the ground and in advance of the preparation of the plans and specifications for an electric

power station, the nature of the soil should be determined, as explained later, because the knowledge of the strata thus gained will aid in determining what class of foundation must be provided. The power of a soil to sustain weight varies according to its nature and condition. The building laws of the larger cities limit the load per square foot on soils, and Table III shows the allowance in a few cities.

TABLE III

ALLOWABLE LOAD PER SQUARE FOOT ON VARIOUS SOILS

| Kind of Soil | Load in Tons (2,000 Pounds) per Square Foot | | | |
|---|---|---|---|---|
| | Philadelphia | Chicago | Buffalo | Milwaukee |
| Solid natural earth of dry clay | $2\frac{1}{2}$ | $1\frac{3}{4}$ | $3\frac{1}{2}$ | 4 |
| Clay, moderately dry | | | | 2 |
| Clay, soft | | | | 1 |
| Gravel and coarse sand, well cemented | | | | 8 |
| Gravel and sand | 4 | | 4 | |
| Clay and sand | | $1\frac{1}{2}$ | | |
| Dry sand confined | | 2 | | |

Rock, according to its kind, may sustain from 18 to 180 tons per square foot, but the load placed per square foot should not exceed one-eighth of the crushing limit. Where the soil is of a yielding nature, **piles** or **grillage** must be used to support the foundations. This kind of work adds considerably to the cost of building, and should be taken into consideration by a careful estimate of cost when selecting property for a station.

**26. Excavation.**—This is a feature of construction work so uncertain in its requirements and cost, and so important in its effects on the future of the structure to be reared, that it is wise before building to make careful tests

over the ground. Test pits should be dug to ascertain the character of the subsoil and consequent depth of excavation required; it is not wise to rely on the experience of others who have built in the vicinity. The earth often varies considerably in short distances, and such contingencies as water, quicksand, rocks that must be blasted away, or soft subsoil requiring piling should be known in advance.

The specifications must provide, and a price be fixed, for each extra cubic foot of excavation found necessary over that originally specified. The keeping of the sides safely shored, and pumping the pit clear of water, should be definitely required. This leaves the responsibility with the contractor, and gives him no chance to demand disproportionately large amounts for work not anticipated. When the ground is not uniform in character, it is necessary to go to a sufficient depth to reach firm dry ground, or the walls of a building erected on it are almost certain to crack because of uneven settlement. Equally serious results follow in the case of a foundation for heavy machinery. It is advisable to pay for this class of work by the cubic yard of *excavation*, not by the cubic yard *excavated.*

**27. Cost of Excavation.**—The cost of excavation varies so much with the locality, on account of the character of the soil, cost of labor, etc., that close figures suitable for general use cannot be given, and the various items should in any particular case be open to competitive bids. The following figures are merely averages of actual bids published in the "Engineering Record" for work in various parts of the United States, and can serve only as an approximation in any particular case: Loam, 32 cents per cubic yard; clay or very stiff soil, 60 cents; rock, $4.20 per cubic yard. The maximum and minimum of the bids on which the foregoing figures were based are as follows: Minimum, loam, 29½ cents per cubic yard; stiff clay, 50 cents per cubic yard; rock, 50 cents per cubic yard. Maximum, loam, 43 cents per cubic yard; stiff clay, 65 cents per cubic yard; rock, $8 per cubic yard.

The reason for the great disparity in the figures is due to the nature of the soil, the amount of excavation, the distance

to the dump, and the cost of labor. There is also a difference in the meaning of the terms used. For example, loam may be very light and sandy or heavy and thick, while rock may mean loose stones, or a practically solid stratum that would have to be removed by blasting, possibly under adverse conditions. The above figures are for depths of about 6 feet. The prices at greater depths increase at the rate of about 50 per cent. for every 6 feet additional depth, over the price for the first 6 feet. For example, if the first 6 feet cost 1, 12 feet would cost 1.5; 18 feet, 2¼; and so on.

**28.** Great care must be taken when excavating near buildings not to undermine or in any manner weaken or injure them; underpinning should be provided. This is especially the case when any quantity of water is encountered, or where great depths of foundations, or blasting is necessary. In the case of rock excavation it must always be borne in mind that the force exerted on surrounding objects by explosives depends on the degree to which the resulting gas is confined. An experienced foreman will proportion the charges to suit the circumstances. The contract should clearly specify that the contractor is to assume all responsibility for danger to adjacent property, and he should furnish a satisfactory bond for this purpose. A sketch showing the shape and all dimensions of the excavation, and its relative position with regard to fixed objects from which the contractor can take his measurements, should always be made a part of the specifications and should be so marked and referred to as to be easily identified. Special examination should be made as to whether water will be encountered, and how the subsoil is affected by it; the specifications should not fail to require all pumping and drainage to be done by the contractor. It is always desirable to extend the excavation to firm soil if consistent with cost. The refilling around finished foundations should be completed to desired grade line, the earth selected to be free from large stones or broken bricks must be rammed as filled in, and puddled and well settled in place.

**29. Piles.**—In case a firm subsoil cannot be obtained by excavation, foundations are supported on **piles**—long posts, driven into the ground by means of pile drivers until they are capable of supporting the load imposed on them. A heavy weight or hammer is raised to a considerable height and allowed to drop on the head of the pile and the process repeated until the pile is driven to the desired depth. The tops of the piles are then evened off to a uniform height and the foundation erected on top.

**30.** Various formulas have been devised for calculating the safe load that a pile will support, but these rules differ considerably because no rule can apply to all conditions. The following formula is very largely used:

$$L = \frac{2\,WH}{p+1} \qquad (1)$$

where $L$ = safe load, in net tons, that the pile is capable of supporting;
$W$ = weight of hammer, in tons;
$H$ = drop of hammer, in feet;
$p$ = penetration, in inches, due to last fall.

This is known as *The Engineering News* formula and gives results that are on the conservative side. It is used in the building laws of a number of cities, for specifying the load on piles. The formula gives the safe load and it is not necessary to allow a factor of safety.

EXAMPLE.—In driving piles for a power-station chimney foundation, the piles were driven until the drop of the hammer produced a movement of .5 inch for each successive drop. The weight of the hammer was 1,500 pounds and the drop 20 feet. What safe load would each pile support assuming that they were driven in firm soil?

SOLUTION.—In formula **1**, we have $H = 20$, $W = \frac{1500}{2000} = .75$ ton, $p = .5$; hence, the safe load would be

$$L = \frac{2 \times .75 \times 20}{.5+1} = 20 \text{ tons. Ans.}$$

The driving requirements for piles in municipal work will

be given in the local building laws, as are also the dimensions, loading, and spacing. Table IV shows the load and spacing for piles in a few cities.

TABLE IV

ALLOWABLE LOAD FOR PILES

| Cities | Piles | Allowable Load Net Tons per Pile |
|---|---|---|
| Philadelphia | Small end, 5 inches; head, 12 inches. Spaced not over 30 inches center to center. | 20 |
| New York | Small end, 5 inches. Spaced not over 30 inches center to center. | 20 |
| Buffalo | Small end, 6 inches. Spaced not over 36 inches center to center. | |

**31. Grillage Work Under Foundations.**—In designing foundations to rest on subsoils of a yielding nature, and where piling is unnecessary or impracticable, provision should be made for uniform settlement. This is particularly important where large generating units are to be erected, as unequal settlement is liable to destroy the alinement. The load may be distributed over a greater area by the use of beams embedded or resting on concrete, making an arrangement usually called **grillage**, as shown in Fig. 10. The columns *a*, *a* carrying the load rest on the beams *b*, which are, in turn, supported by the beams *c* resting on the concrete *d*. By this means the load is spread over a large area and uniform settlement secured.

**32. Setting Foundation Bolts.**—When foundations are built for generators, engines, or other heavy apparatus, it is necessary to locate accurately the holes of the holding-down bolts. It is seldom necessary to make the expensively framed templets often used for this purpose. A far more economical and accurate method is the following: After completing the excavation and laying out of the footing course for the foundation, determine the exact floor level for the finished work, and the exact center lines of the machines to

be set. Lay 2″ × 6″ or 2″ × 8″ timbers on edge, to span the area at, say, 24 inches or 30 inches between centers and having their top edge $\frac{7}{8}$ inch below the floor line. These timbers are laid across the shortest span similar to beams for a floor, and cross-bridged if necessary to retain them in a fixed position. Having located the center lines of the engine or generator unit to be erected, overlay the beams on the lines for the bolt holes with $\frac{7}{8}$″ × 6″ or $\frac{7}{8}$″ × 8″ strips nailed to the beams, being careful to see that the beams shall not interfere with the bolts. If some bolts are higher than others, block up accordingly. On these $\frac{7}{8}$-inch strips, the exact center lines of all bolts can be accurately laid off, and at the center of each bolt a hole bored sufficiently large to pass the bolt neatly. Having hung each bolt in position, slip on it a wooden washer of the thickness of the bedplate, and screw on the nuts. Draw each bolt through the nut as far as it will come on the finished work and allow for the shims to be used in leveling up the bedplate. After the foundation is finished the timbers are removed. This kind of templet is cheap, strong, and, when well laid, more accurate than the framed templet, which often gets twisted.

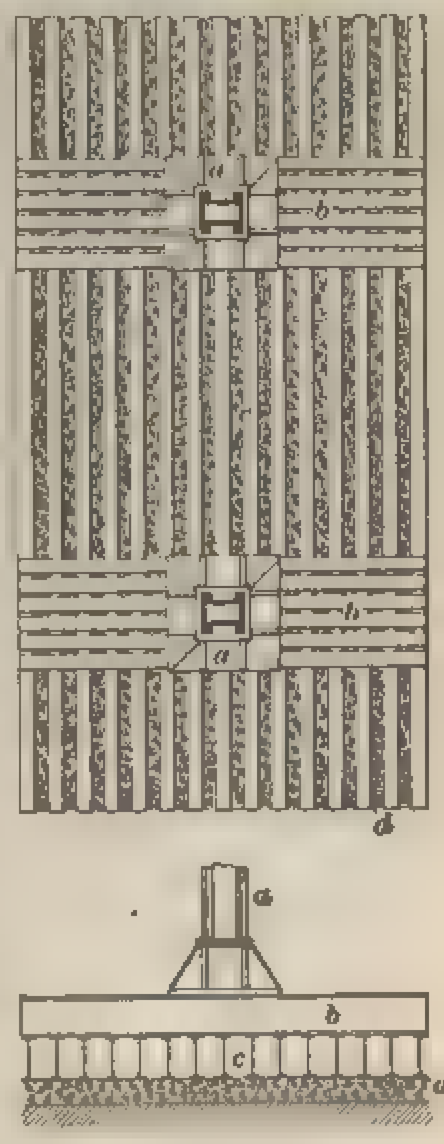

FIG. 10

## IMPORTANCE OF FIREPROOF CONSTRUCTION

**33.** It is very essential that the station building should be of **fireproof construction**, and also should be, as far as practicable, securely protected against fire from adjacent properties. The cost of fireproof construction is not greatly in excess of that which is not proof against fire, and the

saving of insurance premiums, the greater durability, and the sense of security obtained well repays the additional money expended.

**34.** The salient features of this construction are walls of brick, concrete, or stone, the interior face being smooth finished or pointed and the finished walls painted or calcimined with cold-water paint. Wood ceiling or sheathing should be entirely excluded. The roof trusses should be of structural steel, but the roof can be sheathed with 2-inch plank and overlaid with slate, or, for a large building, may have trusses of sufficient strength to carry a fireproof roof. The floors can be laid around the foundations with concrete made of stone, gravel, or cinders, and finished with a granolithic coating. A fire-wall should separate the boiler room from the engine room. The floor of the boiler room will be most durable if laid with vitrified brick on a concrete bed. All doors should be of Underwriters' pattern, made as follows: Two courses of $\frac{7}{8}$-inch matched pine, one course vertical the other diagonal, a layer of $\frac{1}{8}$-inch sheet asbestos between; the wood secured with wrought or wire nails clinched, all exterior surfaces covered with $\frac{1}{8}$-inch sheet asbestos, then entirely overlaid with tin, the joints lock-seamed, nailed, and hammered down over the nails. The doors should be self-closing by hanging on a sloping track and heavy wrought-iron hardware secured by through bolts should be used. Such doors will withstand a more intense heat than sheet-iron doors. Windows on sides exposed to fire from without should be protected with shutters constructed in a similar manner. All switchboard work should be thoroughly fireproof and all precautions taken to avoid short circuits and burn-outs. Wherever conductors pass through walls or floors they should be thoroughly protected by porcelain sleeves.

**35.** Lubricating oils should be stored in a separate fireproof enclosure. Everything about the station should be kept scrupulously clean. In a large station, similar lines of construction will be followed on a more elaborate scale, and

the structural-steel frame will be an important feature. In designing a power station, it should be remembered that the convenient and secure placing of the equipment on the respective foundations is the first and essential feature; the building should be regarded as a suitable enclosure designed to protect the equipment and employes from the elements. Utility should be the first consideration; architectural design is secondary. Every feature that tends toward the economy of operation should be carefully studied out. Very frequently the inconvenient arrangement of the apparatus in a station, or location of floor levels, etc., may require the employment of extra labor, over what would be necessary with a better thought-out plan. The cost of such labor will seldom be less than 5 or 6 per cent. per year on an investment of $10,000.

**36.** In the matter of roofs, preference as to durability, first cost, and least cost of maintenance come in about the following order: Tile laid in cement on concrete, slate laid in cement on concrete, slate laid on plank, slate laid on lath, tin laid on plank, and corrugated iron laid on lath. Metal roofings should be avoided, as they entail a cost for painting and maintenance that is not incurred with a roof of slate, tile, or concrete.

## WATER SUPPLY

**37.** Without a supply of water no electric power station can be operated. A gas-engine station needs it for cooling the engine cylinders; a water-power station for driving the wheels. For a steam-power station it is essential for boiler feeding, and condensing the exhaust steam in case condensers are used. Any deficiency in its purity, reliability, and abundance will affect the economy of the station. The ideal quality of water is rarely found and the best that can be done is to make sure of a constant and unfailing supply sufficient for the successful operation of the station; its deficiencies in quality must be overcome by the method best adapted to make it fit for boiler-feed purposes.

**38.** Having determined on the best source of supply the next step is to ascertain what ingredients are contained in the water, since in its natural form almost all water contains, either in solution or suspension, more or less vegetable and mineral matters. River and lake waters contain from 5 to 20 grains per gallon in solution, and from 10 to 15 grains in suspension. Well and spring waters contain from 10 to 600 grains in solution and little in suspension.

**39.** Practically considered, **boiler scale** is usually formed from carbonates of lime and magnesia, sulphates of lime and magnesia, chlorides, and silicious material. The heat employed to generate steam sets free the impurities held in suspension, and if these are not eliminated before the water is fed into the boiler they are precipitated on the inner surface of the shell and on the tubes to which they firmly adhere in the form of scale.

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## EFFECTS OF SCALE

**40.** Much has been written concerning the waste of heat caused by scale on boiler plates and elaborate theoretical tables have been prepared showing the extra expenditure of fuel required according to the increased thickness of scale; much of this data is unreliable and misleading. Clean boilers are desirable, and thick scale is detrimental, but a scale of $\frac{1}{16}$ to $\frac{1}{8}$ inch does not require the expenditure of any considerable excess of fuel over and above what the same boiler would require with clean plates; the thin scale may prevent pitting of plates and tubes. There can be no doubt but that scale has a detrimental effect on the heat-absorbing power of the plates, but not to the extent frequently claimed. The objection to a thicker scale is that it may cause the metal of the boiler to become heated to such a high degree as to cause burning or bulging of the plates, or some other form of rapid deterioration.

Ordinary boiler scale of a more or less porous character has but trifling effect on the efficiency or capacity of a boiler, until the deposits become so thick as to interfere seriously

with the transmission of heat. A hard, dense scale is more detrimental, depending on quality and thickness, but under scarcely any circumstances will the losses equal those stated in the published tables. Soot and fine ash dust are greater non-conductors of heat than scale and will seriously interfere with capacity and efficiency.

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## IMPURITIES IN WATER

**41.** The analysis of water should be given in grains per United States gallon of 231 cubic inches, which, in round numbers, contains 58,400 grains. To change the figures of an analysis given in parts per 100,000, to grains per gallon, multiply by .584 or, to obtain an approximate figure, by .6. To determine the pounds of scale-forming, or incrusting, solids per 1,000 gallons, divide grains per gallon by 7. Water containing more than 10 grains of incrusting solids per gallon is classed as *hard water*, and water containing from 40 to 50 grains or upwards is liable to foam or prime. The dirt in the water causes it to foam and froth on the water surface in the boiler, which action is apt to lead to *priming;* i. e., the carrying over of water, to the engine, mixed with the steam.

The following is a description of the properties and action of the substances found in waters requiring purification for boiler-feed purposes:

**42. Carbonate of Lime.**—Carbonate of lime is the commonest form in which lime occurs in water. It is but slightly soluble in chemically pure water, but when carbonic acid is present it is found in the form of bicarbonate of lime, which is quite soluble. Bicarbonate of lime, when carried into a boiler, is decomposed by the heat; the carbonic acid is driven off with the steam and normal carbonate of lime is formed, which is practically all precipitated in the boiler when the temperature reaches 290° F. Carbonate of lime alone does not form very hard scale, but it is responsible for a good deal of the mud that is found in boilers. However, it may form part of a very hard scale when materials that cement it to the sides and flues of the boiler are present.

**43. Sulphate of Lime.**—Sulphate of lime (commonly called gypsum or plaster of Paris) is a common constituent of natural water and is responsible for the hardest kind of boiler scale, this scale sometimes being as hard as porcelain. It is almost entirely precipitated when the boiler pressure is at 50 pounds, precipitation being in the form of heavy crystals that at once fasten themselves to the sides of the boiler. Sulphate of lime attaches itself to the sides of a boiler much more firmly than carbonate of lime.

**44. Chloride of Calcium.**—Chloride of calcium is sometimes found in natural water, in which it is very soluble. It is classed among the corrosive minerals found in water. It does not, of itself, form scale, but when other sulphates are present a transfer of acids takes place and calcium sulphate is formed.

**45. Calcium Nitrate.**—Calcium nitrate rarely occurs and is even then of but little importance, as the quantity is usually very small. It, of itself, does not form scale, but in the presence of sulphate of soda an exchange of acids takes place in the boiler and the nitrate is converted into sulphate of lime. Its action is corrosive.

**46. Magnesium Carbonate.**—Magnesium carbonate in its commonest form is used as a toilet preparation; it is then known as magnesia. It behaves in exactly the same manner as carbonate of lime, its bicarbonate being soluble, and its normal carbonate being practically insoluble. Magnesium carbonate is much used as lagging for boilers and is an excellent non-conductor of heat, but when in the form of boiler scale is on the wrong side of the shell.

**47. Magnesium Chloride.**—This is a very objectionable mineral when present in boiler water, it being very corrosive in its action, quickly pitting and grooving boilers that use water containing it.

**48. Magnesium Sulphate.**—Sulphate of magnesium (commonly known as Epsom salts) is a common constituent of natural waters, in which it is extremely soluble. It does

not, of itself, form boiler scale, but is broken up by the lime salts when present in the water, and forms scale.

**49. Sodium Sulphate and Sodium Chloride.**—These salts (commonly known as Glauber's salt and common salt, respectively) do not form boiler scale nor corrode iron; they are not objectionable unless present in very large amounts, when they may cause foaming or priming in the boilers.

**50. Sodium Carbonate.**—This constituent does not form boiler scale nor corrode, but is objectionable when present in large quantity, as it causes foaming.

**51. Iron.**—Iron is generally present in water in the form of bicarbonate, but iron bicarbonate being a very unstable compound, quickly gives out its excess of carbonic acid, and absorbing oxygen is converted into iron rust, this being the cause of many waters turning red when standing exposed to the air for a short time. Carbonate of iron causes boiler scale. Waters from the vicinity of coal beds sometimes contain sulphate of iron, which is extremely corrosive.

**52. Carbonic Acid.**—Carbonic acid is found in all natural waters; it is the same gas as used in soda and seltzer waters and is responsible for the presence of many of the above minerals, as it holds them in solution in the water.

**53. Silica.**—Common sand is nearly all pure silica. Though contained in almost every water, silica is found to the greatest extent in warm waters. It is frequently in combination with alumina, and except in some few cases, is present in such small quantity that it has little to do with the formation of boiler scale.

**54. Acids and Alkalies.**—Water may be alkaline, neutral, or acid; it is generally alkaline. Some waters are acid, although this is quite rare, except where waters are drawn from coal mines or from the vicinity of coal beds. These waters may become quite acid with sulphuric acid, which is produced by the oxidation of the pyrites or sulphide of iron that is always found with coal.

**55. Suspended Matter.**—Organic or inorganic matter may be held in suspension in water and is very variable in quantity, depending on the source of supply of the water and the condition of the rainfall and the season. Suspended matter forms boiler scale only by being cemented to the boiler by other materials.

**56.** There should be no question in the mind of any intelligent engineer regarding the necessity of adopting the most effective methods of purifying and heating the water before it is fed into the boilers. This will not only economize in coal, but also in the cost of cleaning the boilers, and will materially add to their life and durability. The aim should be to collect the scale-forming matter and sediment from the water before it enters the boilers.

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## TESTING FEEDWATER

**57.** To determine what objectionable ingredients are contained in the water, a careful chemical analysis is necessary. If a competent chemist is not accessible the engineer may be able to make the following simple tests. For this purpose the following chemicals and apparatus will be required: One ½-pint bottle of soap solution, one 2-ounce bottle of lime water, one 2-ounce bottle of chloride of barium, one 2-ounce bottle of ferrocyanide of potassium, one 2-ounce bottle of hydrochloric acid, one 2-ounce bottle of nitric acid, one 2-ounce bottle of tincture of cochineal, one 2-ounce bottle of metallic mercury, one 2-ounce bottle of carbonate of ammonia (crystals), one 2-ounce bottle of chloride of ammonia, one 1-ounce bottle of oxalic acid (crystals), one 1-ounce bottle of phosphate of soda (crystals), slips of blue and red litmus paper, one 4-ounce flat-bottom clear-glass bottle, one wooden test-tube holder, one small spirit lamp, ½ pint of alcohol, one test-tube brush, ½ dozen of test tubes.

Fill a clean bottle with the water you desire to test and proceed as follows:

1. *Test for Hard or Soft Water.*—Take a clean test tube and pour into it about $\frac{3}{4}$ inch in depth of the soap solution, then add three or four drops only of the water; if the solution becomes milky or curdly the water is hard. Or dissolve a small quantity of soap in alcohol and put a few drops of the solution in a vessel of water; if the water turns milky, it is hard, if not it is soft.

2. *Test for Acid or Alkali.*—Dip into a test tube half filled with the water, a strip of red litmus paper; if it turns blue the water is alkaline. Dip a strip of the blue litmus paper into the water; if it turns red the water contains acid.

3. *Test for Carbonic Acid.*—Pour about $\frac{3}{4}$ inch of water into a test tube and then pour in the same quantity of lime water; if carbonic acid is present the water will become milky; on adding a little hydrochloric acid, the water will become clear again.

4. *Test for Sulphate of Lime or Gypsum.*—Pour water to the depth of $1\frac{1}{2}$ inches in a test tube and add a little chloride of barium; if a white precipitate is formed and will not redissolve when a little nitric acid is added, sulphate of lime is present.

5. *Test for Magnesia.*—Fill a test tube one-fourth or one-third full of water, hold it with the tube holder, and bring it to the boiling point over the spirit lamp; then add the point of a knife full of carbonate of ammonia, and a very little phosphate of soda; if magnesia is present it will form a white precipitate, but as it may not do so at once it is better to set it to one side for a few minutes.

6. *Test for Lead.*—Fill a test tube one-fourth full of water and add one or two drops of tincture of cochineal; if there be but a trace of lead in the water the solution will be colored blue instead of pink.

7. *Test for Copper.*—Add to some water in a test tube a little filing dust of soft iron and a few drops of chloride of ammonia; a blue colorization denotes the presence of copper.

8. *Test for Iron.*—To some water in a test tube add one drop of ferrocyanide of potassium; the water will become blue if iron is present.

**58.** The following simple tests may also be used and under some conditions may be found more convenient than those previously given:

1. *Earthy Matter, or Alkali.*—Dip litmus paper into vinegar; if on immersion in water the paper returns to its former shade, the water contains earthy matter or alkali.

2. *Carbonic Acid.*—Take equal parts of water and clear lime water. If combined or free carbonic acid is present, a precipitate will be produced, in which, if a few drops of hydrochloric acid is added an effervescence will take place.

3. *Magnesia.*—Boil the water to one-twentieth part of its weight, drop a few grains of neutral carbonate of ammonia and a few drops of phosphate of soda into it; a precipitate will be formed if magnesia is present.

4. *Iron.*—Dissolve a little prussiate of potash and mix it with the water; the water will become blue if iron is present.

5. *Lime.*—Put two drops of oxalic acid into a glass of water and blow on it; if the solution becomes milky, it indicates the presence of lime.

6. *Acid.*—Immerse a piece of blue litmus paper in the water; if it turns red, the water is acid. If it forms a precipitate on adding lime water, carbonic acid is present.

## IMPROVEMENT OF WATER BY CHEMICAL TREATMENT

**59. Kennicott Water Softener.**—A successful method now employed for the softening of water before it is fed into the boilers, is that brought out by the Kennicott Water Softener Company. The result is accomplished by chemical purification, the ingredients (lime, soda, or other neutralizing agents) being introduced into the "raw" water in accurate proportions. Fig. 11 (*a*) shows a cross-section of the apparatus and (*b*) a plan looking down on top.

The machine consists of a steel settling tank *a* provided with a conical bottom *b*. In the center of this tank and open at the top and bottom is a cone-shaped conduit or downtake *c* within which is a tank *d* for the preparation of the lime water; this tank is, of course, closed at the bottom. The

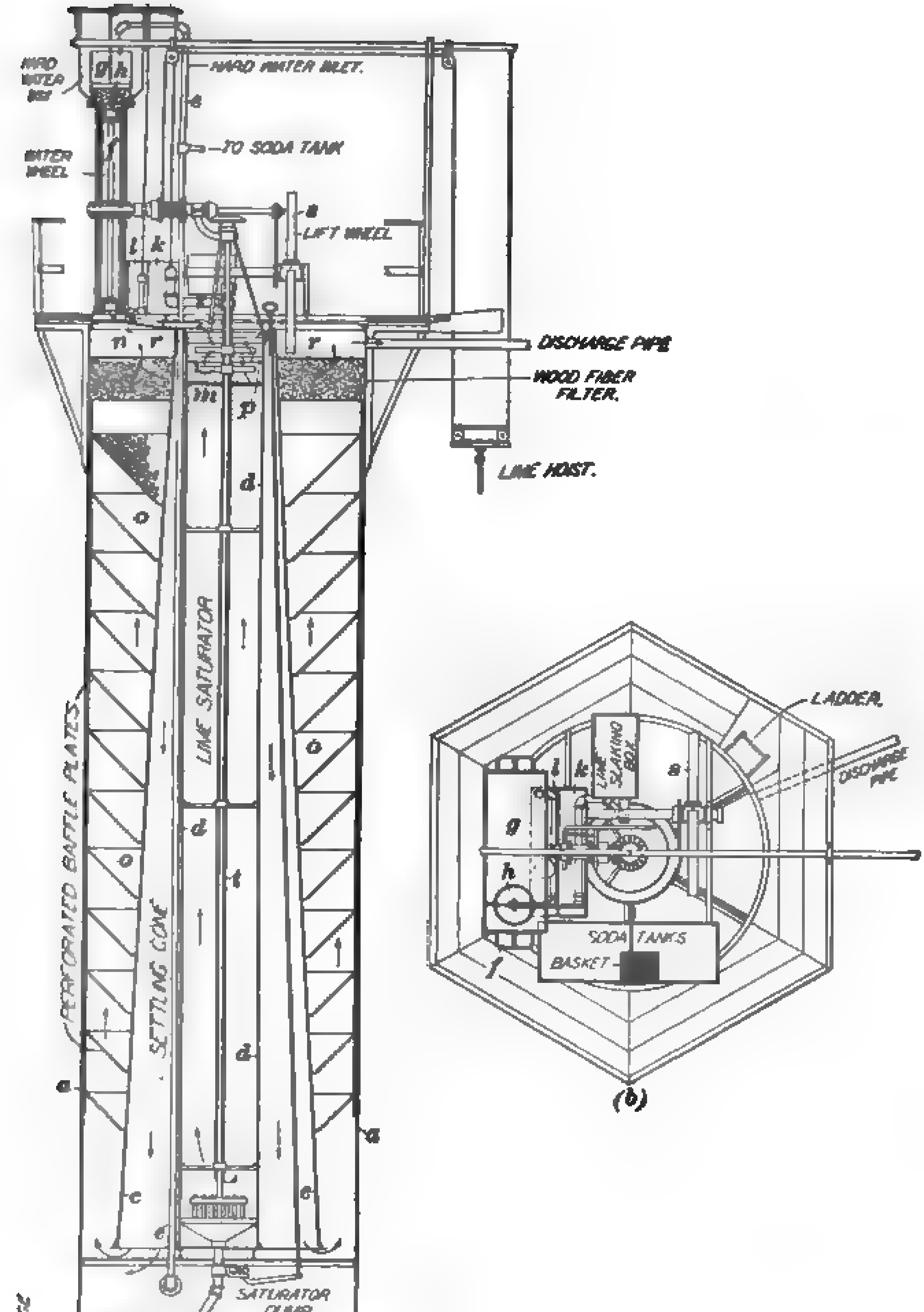
HARD WATER INLET.
TO SODA TANK
WATER WHEEL
LIFT WHEEL
DISCHARGE PIPE
WOOD FIBER FILTER.
LIME HOIST.
LIME SATURATOR
PERFORATED BAFFLE PLATES
SETTLING CONE
SATURATOR DUMP
DUMP
SLUDGE DISCHARGE
(a)
LADDER.
LIME SLAKING BOX
DISCHARGE PIPE
SODA TANKS
BASKET
(b)

FIG. 11

lime-saturator tank is enclosed in the conduit so that danger from freezing of water in small parts is obviated. The supply pipe *e* runs through the body of the apparatus for the same reason. On the top of the tank is placed a cast-iron overshot waterwheel *f*, which furnishes all the power necessary to operate the apparatus. The water from the source of supply is delivered to the hard-water box *g* above the top of the settling tank; from this it passes through a slot in the bottom, the size of the slot being adjusted according to the amount of water to be treated. Within this box is a float *h* with chains passing over pulleys and connected to hinged inlet pipes in the two boxes or small tanks *k*, *l* that contain soft water and the soda solution, respectively. The object of this arrangement is to vary the supply from those tanks in accordance with the supply of raw water. Thus, if the rapidity of the supply increases so as to maintain a depth of 6 inches in the box, or a head of 6 inches over the slot in the bottom of the box, the rising of the float will allow the ends of the hinged inlet pipes to drop 6 inches below the surface of the respective tanks, thus maintaining a constant uniform head. The ends of these hinged inlet pipes are closed with caps, each cap having a small slot of such size as to give the required proportion of solution to the water. This, of course, varies according to the character of the water to be treated.

**60.** In order to separate the lime and magnesia from the water a solution of lime water is added. The lime and magnesia are in the form of soluble bicarbonates, but when lime water is added these change to carbonates, which are insoluble and therefore settle out. This method of treatment was discovered by Doctor Clark, an English scientist. In order to remove the sulphates, chlorides, and nitrates of lime and magnesia, the water is treated with a solution of sal-soda or soda ash, which leaves in the water harmless sodium sulphate and sodium chloride. This method of treatment was discovered by Doctor Porter, another English scientist, and the whole process of treatment is often referred

to as the *Porter-Clark* process of water softening. In the Kennicott softener, some of the water that has been softened is used to make up the lime solution, as it is found that less lime is required than if hard water is used.

Referring to Fig. 11 (*a*), the flow of water is indicated by the arrows. The hard water flows up through pipe *e*, discharges into box *g*, and flows over the waterwheel *f* into the top of the cone. At *n*, the soda solution is introduced in the proper proportions. In the upper part *p* of the lime-saturator tank the water is thoroughly mixed, by means of revolving paddles, with the lime water, which flows up through a perforated plate *m*. The water then enters the top of the settling cone, in which its velocity continually decreases, causing the particles held in solution to fall to the bottom of the cone, the larger particles carrying the smaller ones with them. On reaching the bottom of the tank, the current is reversed, and the water rises through a series of perforated conical baffle plates *o*, *o*; at the same time the velocity continues to decrease, owing to the increasing diameter of the water space. On reaching the top, the water passes upwards through a filter compartment filled with wood fiber, and enters a shallow soft-water tank *r* from which it flows to the storage tank for supplying the boilers. At the bottom of the settling tank is a conical hopper with valve for discharging the sediment. The soft water for making the lime solution is lifted from tank *r* to tank *k* by means of a lift wheel *s* driven by the waterwheel and provided with curved buckets that discharge the water through a hollow shaft into tank *k* from which the water flows to the bottom of the lime saturator through the pipe *t*. The elevation of tank *k* gives sufficient head to make the lime water in the saturator come up through plate *m* to be mixed with the hard water. The waterwheel is also arranged so that, by throwing in a clutch, it can be used for operating a hoist for raising the lime and soda to the top of the tank. The whole apparatus is automatic in its action and the only attendance necessary is that to keep up the supply of chemicals. It is claimed that the expense per thousand gallons of water purified is as follows: For the

cost of chemicals, 3 cents; for interest on investment, $\frac{1}{2}$ cent; for attendance, $\frac{1}{2}$ cent; making a total cost of approximately 4 cents, which in especially adverse conditions might be increased to 5 cents.

**61. Extra Cost Due to Impure Water.**—While much has been written and many investigations made about the use of impure water and the resultant cost, the data connected therewith has probably never been so well assembled as by the American Railway Master Mechanics Association. A committee appointed on this particular subject has accumulated sufficient evidence to show that the cost of using impure waters in locomotive boilers is as follows:

| | |
|---|---|
| Cost of extra cleaning per boiler per year | $ 50 |
| Cost of extra repairs per boiler per year | 360 |
| Cost of extra fuel per boiler per year | 340 |

making a total of $750 extra cost per boiler per year due to the use of bad water.

## PURIFICATION OF WATER BY LIVE STEAM

**62.** Many of the impurities are precipitated and form scale when the water is heated to the high temperature corresponding to the steam pressure maintained in the boiler. It follows therefore that if some device is provided in which the feedwater can be heated up to or near the temperature of the water in the boiler, the impurities can be precipitated before the water is fed into the boiler. These devices might be called *combined heaters and purifiers*, but since they usually use live steam they are often called **live-steam feedwater heaters.** They are made in a variety of forms; some are constructed with removable pans for collecting the scale-forming material, while others depend on the use of a blowoff and occasional opening up of the heater for the removal of the sediment.

**63.** Fig. 12 shows a **Hoppes purifier,** which is of the removable-pan type. It consists of a cylindrical shell *a* fitted on one end with a removable head *b*, shown in the figure as

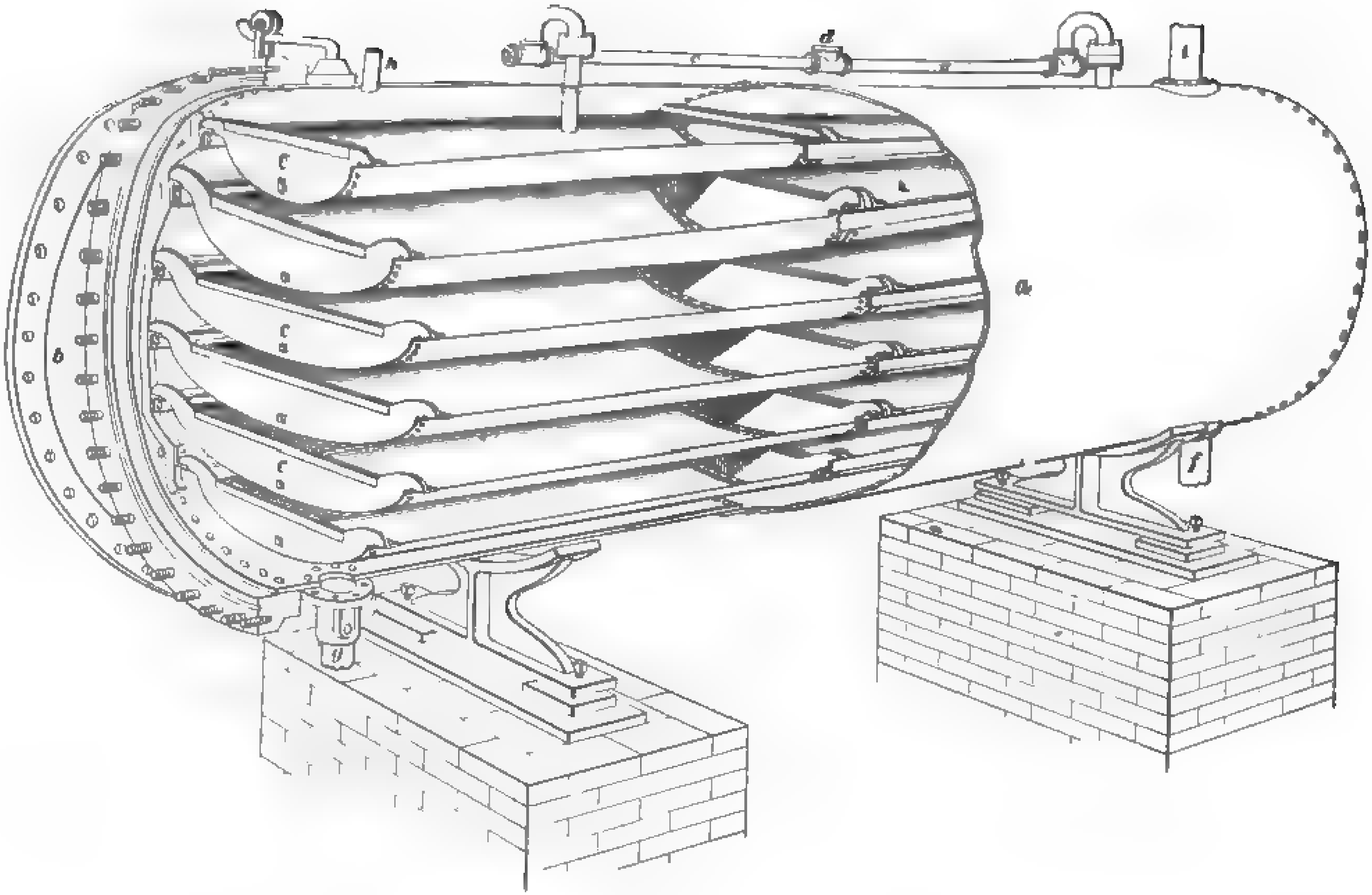

FIG. 12

taken off and swung out of the way; a series of shallow steel pans *c, c* are placed within the purifier. The feedwater enters at *d* and flows through the branch pipes *e, e* into the top pans, from which it flows in thin sheets over the edges of the pans and finally out of the purifier through the pipe *f*. Live steam from the boiler enters through the pipe *i* and heats the water in the purifier to a temperature nearly equal to its own, and in so doing precipitates those impurities that become insoluble by heat. Mud and earthy matter deposit on the inside of the pans while the scale-forming substances coat the outside; the pans are removed occasionally and cleaned. The feedwater flows through *f* into the boiler by gravity, the purifier being placed higher than the boiler and having a pressure equal to that in the boiler within it. A blow-off pipe is connected at *g* and a glass water-gauge connects to *g* and *h*.

Fig. 13 shows the arrangement of a live-steam purifier in connection with an exhaust-steam heater. The exhaust steam from the engines passes through the exhaust pipe *a* into the heater *b* where it meets the cold feedwater delivered from pipe *c*. The exhaust steam heats the water to a temperature of, say, 206° to 210°. From *b* the water is pumped by the boiler feed-pump *d* into the live-steam purifier *e*, which is supplied with live steam through pipe *f*; hence, the water must be pumped in against the boiler pressure. The purifier is arranged above the level of the boilers, so that the water can run in by gravity through pipes *g*.

Should the station be so situated that it must use, for boiler feed, water that is highly impregnated with incrusting materials, such as carbonates and sulphates of lime and magnesia, it may be decided to use a live-steam purifier, but it should only be used as a last resort since it is more economical to use, if possible, sources of waste heat for heating the feedwater.

When the water contains in solution such ingredients as can be neutralized or rendered harmless by the addition of substances, such as caustic soda, kerosene oil, or trisodium-phosphate, it is desirable to add the neutralizing agent before

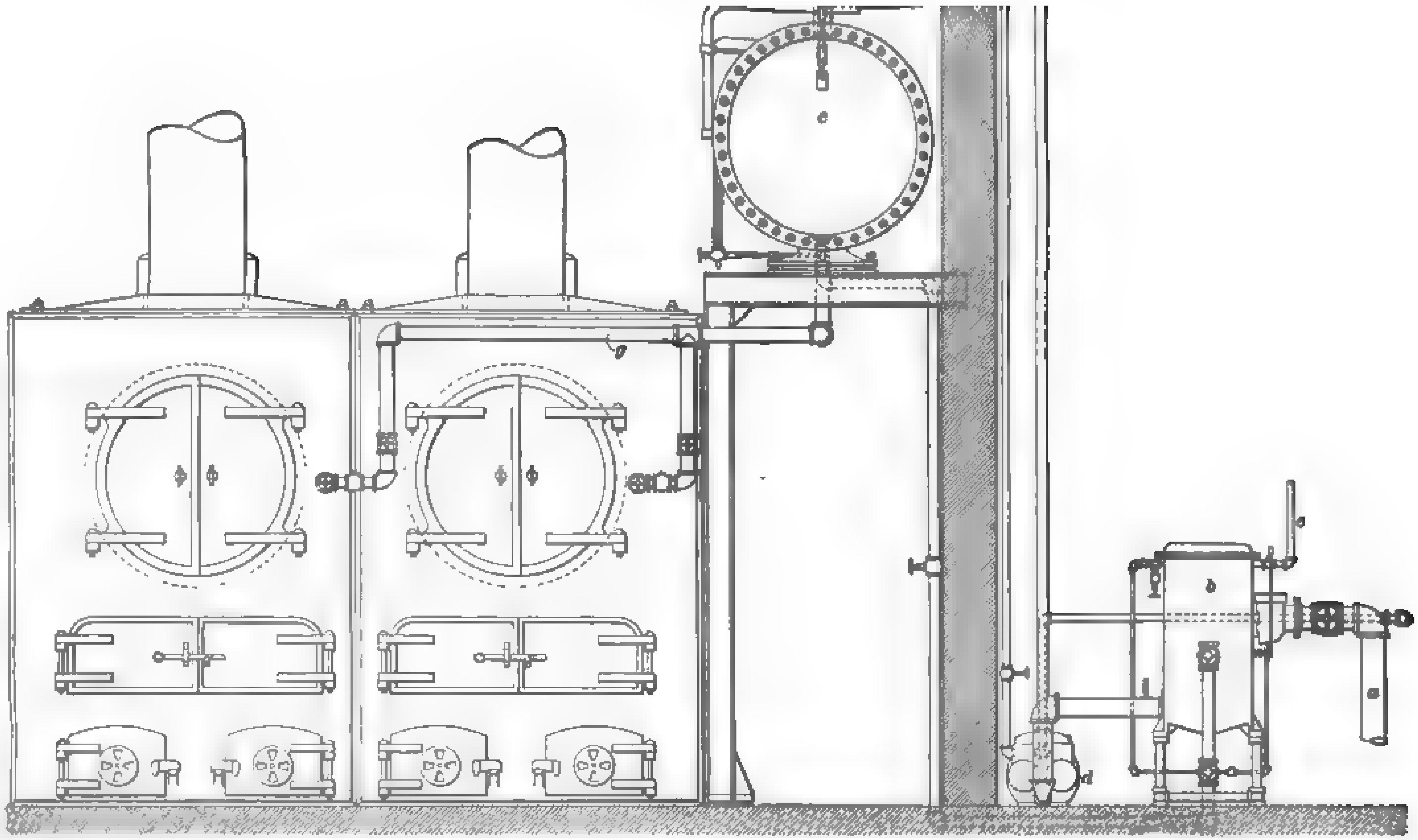

FIG. 18

the water enters the heater. The supply may be stored in a barrel or tank and fed regularly in the proper proportions by a suitable appliance. Kerosene oil fed into a boiler has the effect of loosening scale and preventing its adherence to the tubes. The oil is fed in by a device very similar in appearance to the lubricators used for engine cylinders.

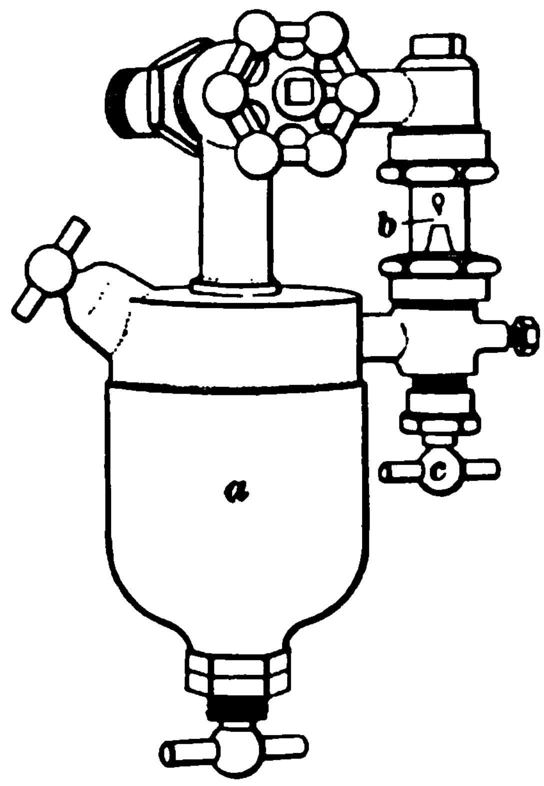

FIG. 14

Fig. 14 shows a *boiler oil injector*, as it is called. The oil is contained in the reservoir *a* and passes through the glass tube in the form of drops on its way to the boiler. The attendant can therefore see the amount supplied and regulate it, as may be required, by means of the valve *c*.

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## HEATING FEEDWATER

**64.** The feedwater furnished to steam boilers must of necessity be heated from its normal temperature to that of steam before evaporation can commence, and if not otherwise accomplished, the heating will be done at the expense of fuel that should be utilized in making steam. This temperature at 75 pounds pressure is 320°, and if we take 60° as the average temperature of feedwater, we have 320 − 60 = 260 British thermal units of heat required to raise 1 pound of water from 60° to 320°. It requires 1,151 heat units to convert a pound of water at 60° into steam at 75 pounds pressure, so that the 260 units required for heating the water represents about 22.6 per cent. of the total. All heat, therefore, that can be imparted to the feedwater before it enters the boilers is just so much saved, not only in cost of fuel, but in capacity of boiler. It must be remembered that of the total heat generated in the furnace of the boiler, nearly 80 per cent. is lost and cannot be converted into mechanical power on account of the low efficiency of the steam engine

as a heat engine. Therefore, the sources of waste heat must be utilized, and the question of the proper selection of auxiliary appliances to obtain from this waste the largest possible benefit becomes of first importance. The unused heat units have cost just as much in proportion to the price paid for the fuel as the useful units; hence, in the interest of economy, the largest possible percentage of the heat units that would otherwise be wasted must be returned to the boiler and thereby utilized.

**65. Sources of Waste Heat.**—The principal sources of waste heat are as follows: First, the exhaust steam from engines; second, the exhaust steam from pumps and auxiliary appliances; third, the heat carried off by the gases passing from the furnace through the flues and up the stack. In one case we have the heat rejected with the exhaust steam, which may be utilized in one or more of the numerous types of heaters, and in the other case we have the heat of a higher temperature rejected by the boiler furnaces. Of the several methods of deriving benefit from these escaping heat units, the least in cost are those employing exhaust-steam heaters. The economizer method, or the method of making use of the waste heat in the furnace gases, is the more expensive, but under certain conditions it is desirable.

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## SELECTION OF EXHAUST STEAM FEEDWATER HEATER

**66.** The ingredients contained in the water will largely determine the type of exhaust-steam heater to be used in any given plant. These heaters are divided into two general classes, known as *open heaters* and *closed heaters*. An **open heater** may be defined as one in which the water is in contact with the atmosphere. In a direct-contact open heater, the exhaust steam comes into contact with the water, which, by means of suitable devices, is broken into spray or thin sheets in order to readily absorb the heat of the steam. In a coil heater, the exhaust steam passes through coils of pipe submerged in a suitable vessel containing the water to be heated and open on top. **Closed, exhaust-steam,**

**feedwater heaters** may be defined as heaters in which the feedwater is not exposed to the atmosphere, but is subjected to the full boiler pressure. The steam does not come into contact with the water; the latter is heated through coming into contact with metallic surfaces, generally those of tubes, that are heated by the exhaust steam.

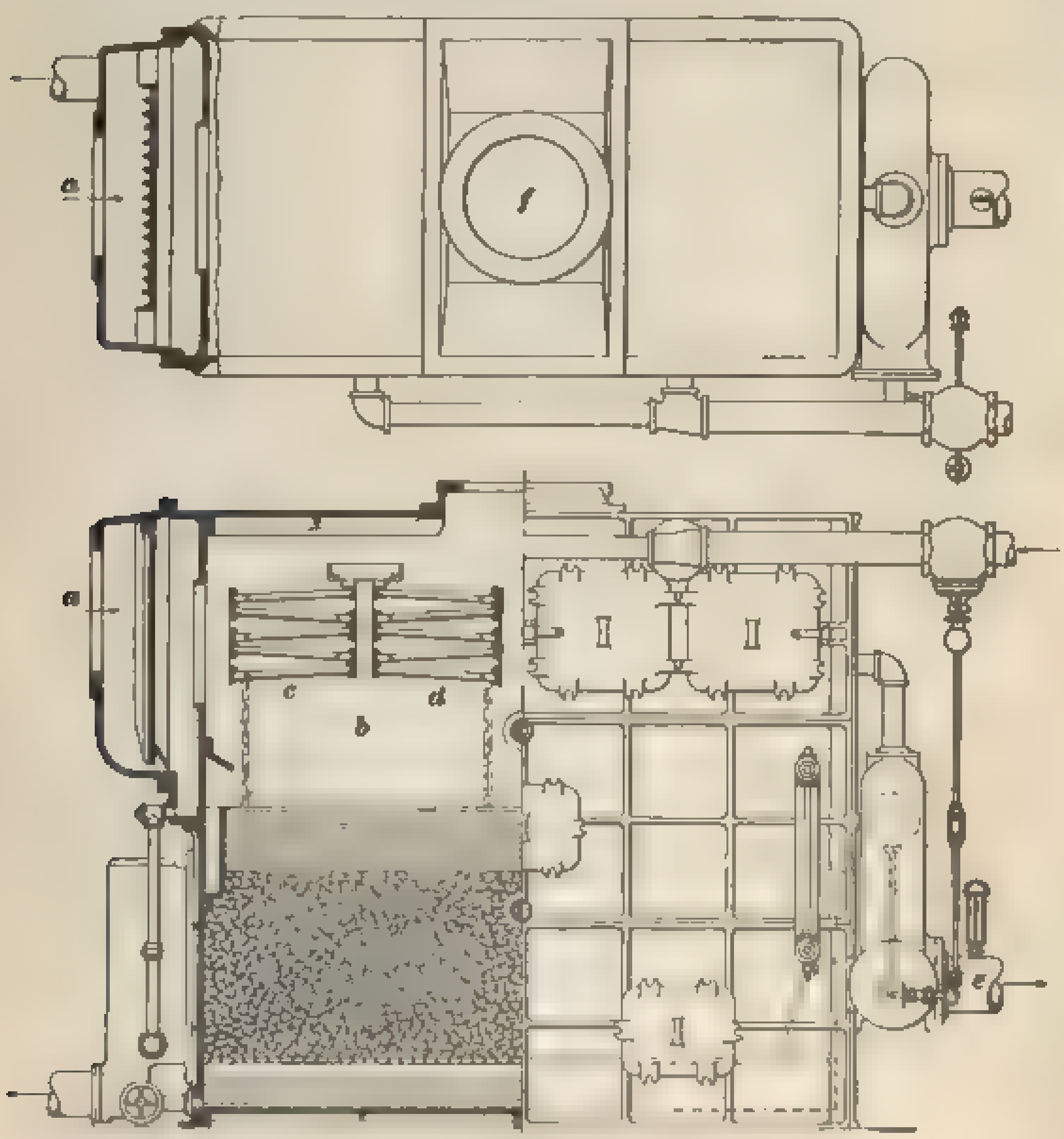


FIG. 15

**67. Cochrane Heater.** Fig. 15 shows the **Cochrane heater**, which will serve as an example of the open type. This heater serves also as a purifier. The exhaust steam enters at *a* and passes into the chamber *b*, where it comes into contact with the cold feedwater, which flows over the trays *c d*;

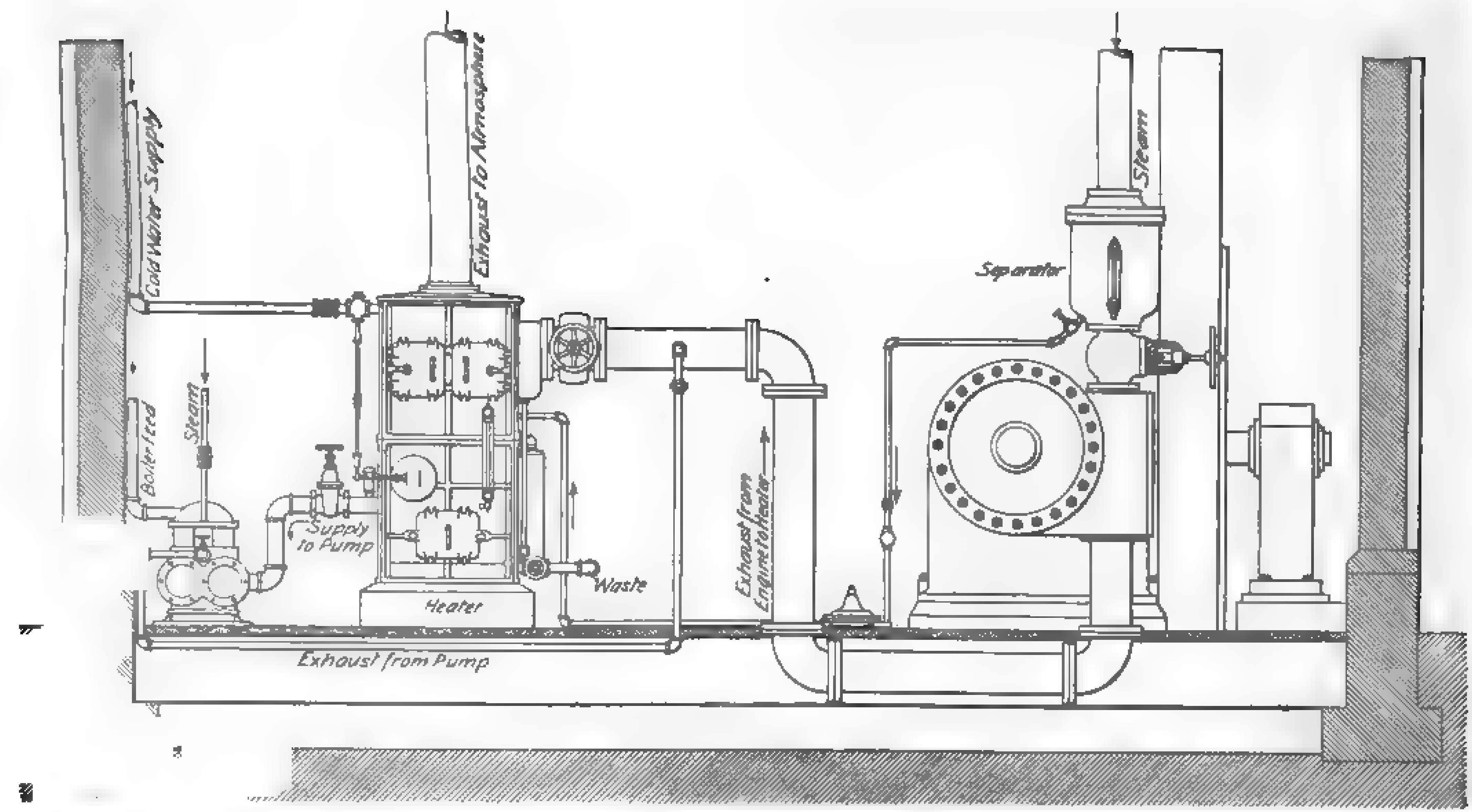
Cold Water Supply
Boiler feed
Steam
Exhaust to Atmosphere
Supply to Pump
Heater
Waste
Exhaust from Pump
Exhaust from Engine to Heater
Separator
Steam

FIG. 16

this exposes a large surface of water to the steam. The heated water collects in the lower part, filters through a thick layer of coke, and is drawn off by the boiler feed-pumps attached to the outlet *e*. The exhaust steam passes out at the outlet *f* on top of the heater. Fig. 16 shows a Cochrane, open, exhaust-steam heater connected to an engine and boiler feed-pump.

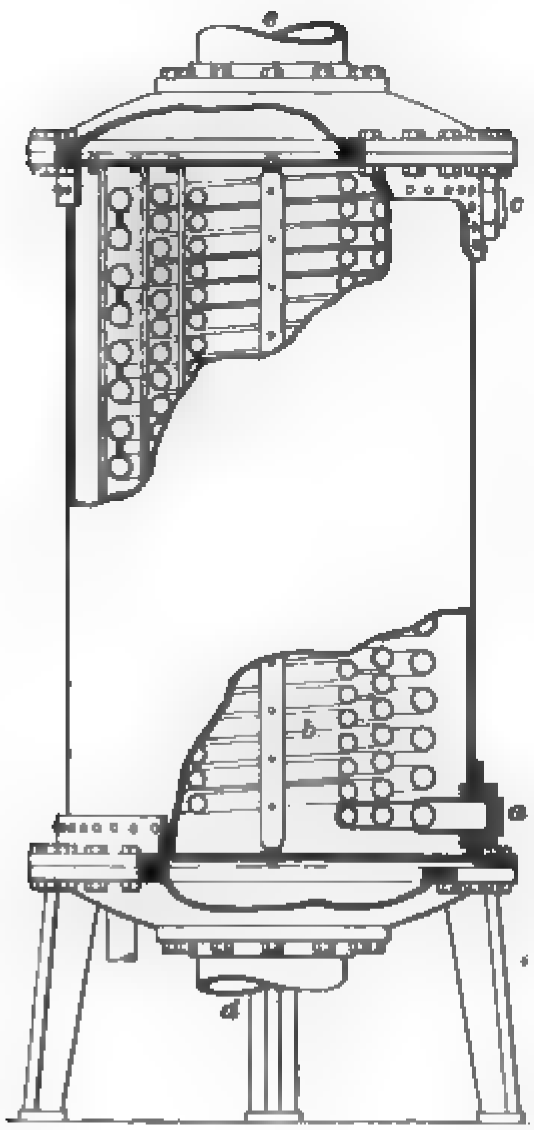

FIG. 17

**68. Closed Heaters.** Fig. 17 shows an American feed-water heater, which is of the closed type. The feed-water enters at *a*, passes through the triple pipe coil *b*, and out at *c*; the exhaust steam enters at *d* and passes out at *e* after passing between the coils of the pipe and heating the water contained therein. Fig. 18 shows a Berryman heater, which is of the closed type also. The heating surface is obtained by means of tubes *a*, *a* through which the exhaust steam passes. The steam enters the bottom *b* of the heater through the pipe *c*, and there being a steam-tight partition in the bottom, is caused to flow up through one leg of the tubes and down the other and thence through pipe *d* to the atmosphere. The condensed steam is discharged through the drip *e*. The feed-water enters the heater through pipe *f* and leaves at the top through the feedpipe *g*. A safety valve *h* is fitted to the heater, which prevents any overpressure due to a closing of the globe valve in the feedpipe before the pump is stopped. When the safety valve is open, the water discharges through

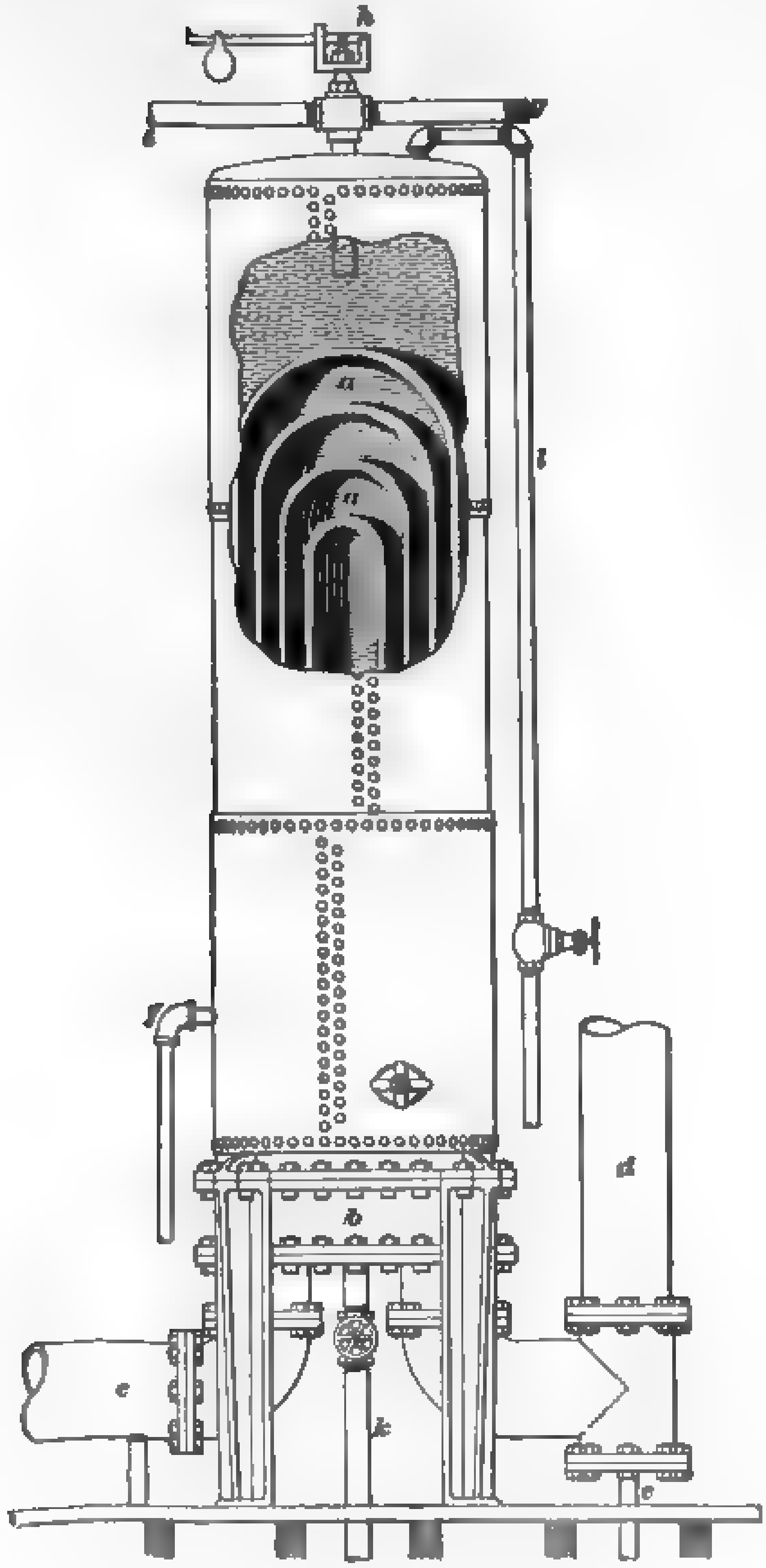


Fig. 18

*i* to the sewer. The heater is fitted with a bottom blow-off *k* and a surface blow-off *l* for removing settled and floating impurities in the water. It heats the water to a temperature between 200° and 212°, and in so doing precipitates the scale-forming substances that become insoluble at these temperatures.

Where the boiler feedwater is free from acids, salts, sulphates, and carbonates so that no scale is formed under a high temperature, the closed feedwater heater will be found satisfactory. This kind of water is not available in the majority of places. Heaters of the coil type may be used with pure water, but should not be used with water that will precipitate sediment or scale-forming matter of any kind, because they have no sediment chamber. The coil heater is very efficient as a heater, as the water circulating through the coils is a long time in contact with the surface surrounded and heated by the exhaust steam. Heaters of the closed type with straight tubes and sediment chamber can be more readily cleaned than those having curved tubes, but the curved tubes allow more freedom for expansion and contraction. Heaters of the tubular type should have ample sediment chambers and may be used with water that contains organic matter or earthy matter, but not with scale-forming ingredients. Carbonate of lime is liable to combine with earthy matter and form an exceedingly hard scale.

**69.** Heaters of the open exhaust-steam type have the advantage of bringing the exhaust steam in direct contact with the feedwater; some of the exhaust steam is condensed (thus effecting a saving in feedwater) and sediment and scale-forming ingredients (excepting the sulphates of lime and magnesia) are precipitated or will settle to the bottom of the heater. The oil in the exhaust steam must be intercepted by special oil extractors, filters, or skimmers, generally combined with the heater and, by automatic regulation, sufficient fresh feedwater is added to make up the total quantity required. The open heater is available for heating and purifying where the impurities do not require a temperature exceeding 275° for precipitation. When the system is

properly arranged all live-steam drips and discharge from traps will be discharged into the heater.

**70.** Table V shows the percentage of the lime thrown down from feedwater at various temperatures. A temperature of 290° F. is necessary for the precipitation of all the lime.

TABLE V

PERCENTAGE OF LIME PRECIPITATED FROM WATER AT VARIOUS TEMPERATURES

| Temperature Degrees Fahrenheit | Per Cent. of Lime Thrown Down | Temperature Degrees Fahrenheit | Per Cent. of Lime Thrown Down |
|---|---|---|---|
| 217 | 50.0 | 245 | 77.4 |
| 219 | 52.3 | 250 | 81.7 |
| 221 | 56.8 | 255 | 86.0 |
| 227 | 60.5 | 261 | 90.3 |
| 232 | 64.5 | 266 | 94.0 |
| 236 | 69.0 | 271 | 97.7 |
| 240 | 73.3 | 290 | 100.0 |

## HEATING SURFACE OF FEEDWATER HEATERS

**71.** When determining the size of closed heater required for any given plant, the following quantities should first be obtained: The maximum weight of water to be heated per hour, the natural temperature of the water entering the heater, the temperature of the steam, and the temperature to which the water must be heated. A standard boiler horsepower has been defined by the American Society of Mechanical Engineers as equal to the absorption of 33,330 British thermal units per hour. This is equivalent to the evaporation of 34.5 pounds of water per hour at 212° F. into steam at 212° F. or of 30 pounds of water at 100° F. into steam at 70 pounds pressure. The number of square feet of tube surface required for each boiler horsepower can be calculated from the formula

$$S = .248 \log \frac{T_s - T_1}{T_s - T_2} \qquad (2)$$

where $S$ = square feet of tube surface per horsepower, or the surface required to heat 34.5 pounds of water per hour;

$T_s$ = temperature of steam passing through heater;

$T_i$ = temperature of water entering the heater;

$T_e$ = temperature of water leaving the heater.

The horsepower of heater per square foot of surface is $\frac{1}{S}$. The value of $S$ given by the formula is for copper tubes.

**TABLE VI**

**AREA OF HEATING SURFACE REQUIRED IN FEEDWATER HEATERS PER BOILER HORSEPOWER**

| Initial Temperature of Feedwater Degrees Fahrenheit | Temperature of Water When Fed Into the Boiler Degrees Fahrenheit | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 180 | | | 190 | | | 200 | | | 210 | | |
| | Square Feet of Heating Surface Required for | | | | | | | | | | | |
| | Copper | Brass | Iron | Copper | Brass | Iron | Copper | Brass | Iron | Copper | Brass | Iron |
| 50 | .17 | .19 | .28 | .21 | .23 | .34 | .27 | .29 | .43 | .39 | .42 | .63 |
| 60 | .16 | .18 | .27 | .20 | .22 | .33 | .26 | .28 | .42 | .38 | .41 | .62 |
| 70 | .15 | .17 | .26 | .19 | .21 | .32 | .25 | .27 | .41 | .37 | .40 | .61 |
| 80 | .14 | .16 | .24 | .18 | .20 | .30 | .24 | .26 | .40 | .36 | .39 | .60 |
| 90 | .13 | .15 | .23 | .17 | .19 | .29 | .23 | .25 | .38 | .35 | .38 | .58 |
| 100 | .12 | .14 | .21 | .16 | .18 | .27 | .22 | .24 | .36 | .34 | .37 | .56 |
| 110 | .11 | .13 | .20 | .15 | .17 | .25 | .21 | .23 | .34 | .33 | .36 | .54 |
| 120 | .10 | .12 | .18 | .14 | .16 | .24 | .20 | .22 | .33 | .32 | .35 | .53 |
| 130 | .09 | .10 | .16 | .13 | .15 | .22 | .19 | .20 | .31 | .30 | .34 | .51 |

For brass or iron tubes larger areas will be required; these can be obtained by multiplying the result given by the formula by 1.12 for brass tubes and 1.67 for iron tubes.

**Example.**—What area of copper-tube surface will be required for a 100-horsepower heater that is supplied with steam at 215° F. and is to heat the water to 190° F., the temperature of the feedwater being 60° F.

SOLUTION.—In formula 2, $T_s = 215°$, $T_i = 60°$, $T_a = 190°$; hence $S = .248 \log \frac{215 - 60}{215 - 190} = .248 \log \frac{155}{25} = .20$ nearly; hence, for 100 H. P. the tube surface should be $.20 \times 100 = 20$ sq. ft. Ans. If iron tubes were used the area would be $20 \times 1.67 = 33.4$ sq. ft.

**72.** Table VI shows the area of copper heating surface required per horsepower for initial temperatures of feedwater ranging from 50° to 130° and final temperatures ranging from 180° to 210°. A boiler horsepower is taken as equivalent to an evaporation of 34.5 pounds of water per hour from and at a temperature of 212° F. The temperature of the steam in the heater is taken as 215°, because the pressure in the heater is always slightly in excess of atmospheric pressure.

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## HEATING BY WASTE FLUE GASES

**73.** The gases going to the chimney carry off, on an average, according to good authority, from 15 per cent. to 50 per cent. of the heat units contained in the fuel. Some portion of this heat is always available for heating the feedwater, by using what are known as **economizers**, and frequently the feedwater may be carried nearly to the temperature of high-pressure steam, making a saving in some instances of 30 per cent. The heating surface of the economizer intercepts and absorbs a large percentage of the heat from the gases passing to the chimney. The more wasteful the boiler, the greater is the benefit derived from the economizer; but for large plants it is always a valuable adjunct, and particularly where condensing engines are used. In many cases water having been heated by exhaust steam may be raised to a much higher temperature by being passed through an economizer.

Fig. 19 illustrates a Green fuel economizer. It consists of groups of vertical tubes *h* connected into headers *k* and so arranged that the water may be forced through the tubes in a direction opposite to the flow of the hot gases circulating around them. Thus the water enters at *f* and the coolest gases meet the coolest water; as the water becomes heated

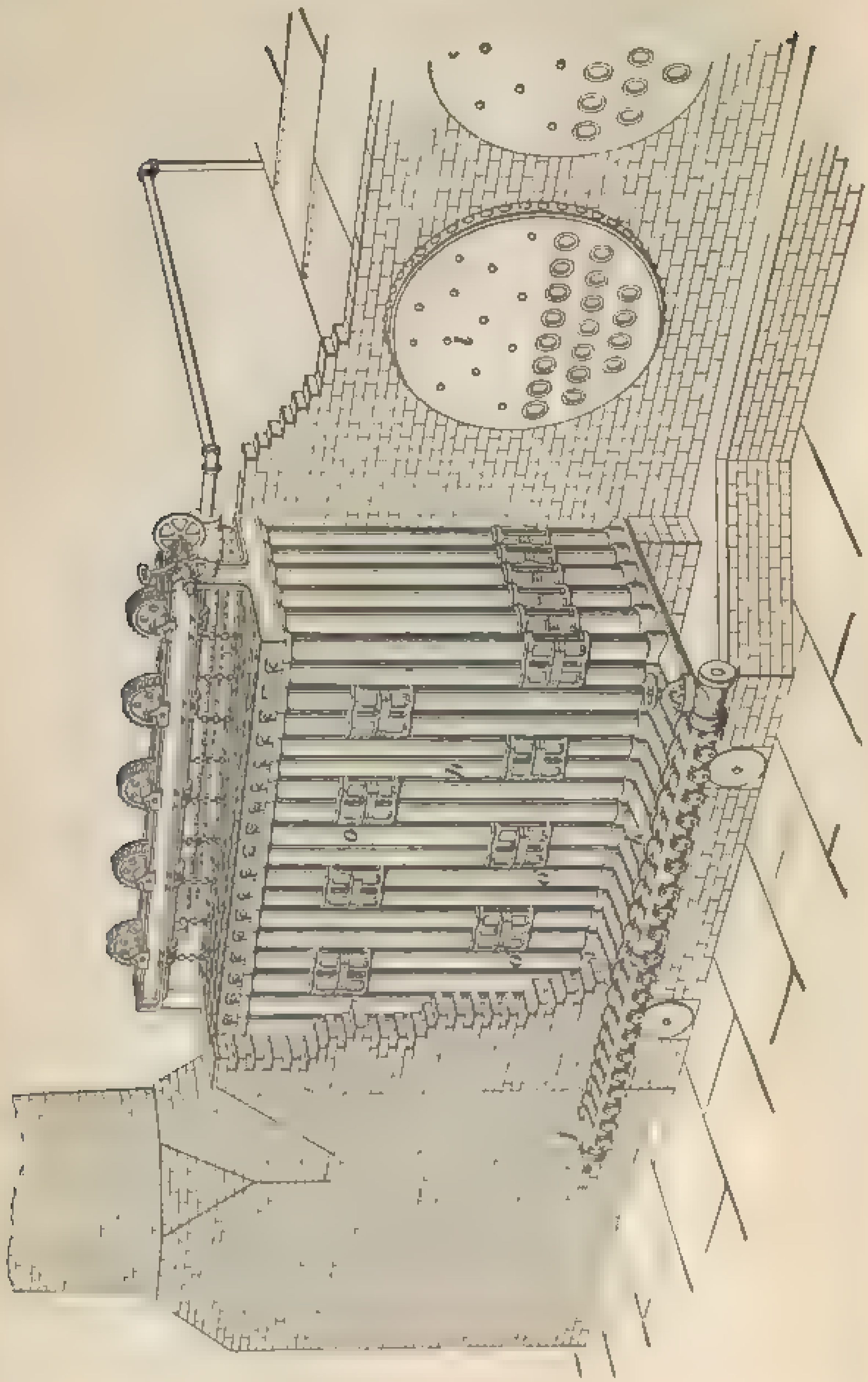

FIG. 19

by passing to the right it comes into contact with the hotter gases nearer the boiler. The economizer is placed in an enclosing chamber, usually of brick, through which the gases pass on their way from the boilers *l* to the chimney. Fig. 20 shows a typical arrangement of economizer with a by-pass flue for use in case it is desired to shut off the gases from the economizer.

No economizer is complete without some device for cleaning the soot and ashes from the tubes, because a coating of soot retards the absorption of heat from the gases by the water. In the Green economizer this cleaning is effected by

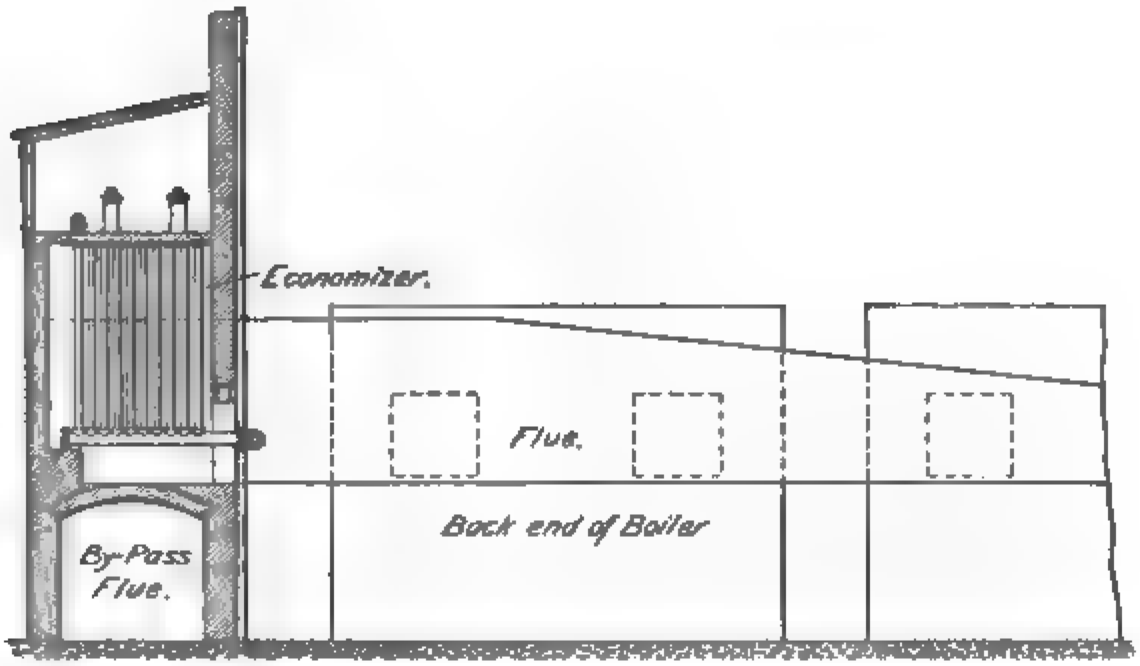


FIG. 20

scrapers *o*, *o* that are slid slowly up and down the tubes by means of suitable gearing. Cast-iron pipes are used to avoid pitting and corrosion, to which wrought-iron pipes are subject. The temperature to which an economizer can raise the feedwater depends on the temperature of the gases leaving the boilers. Where sufficient boiler heating surface is used to reduce the gases to a low temperature before their discharge to the chimney, economizers will not be of so great advantage as where less boiler heating surface is applied.

**74.** The economy resulting from the use of an economizer depends on the temperature at which the feedwater is

supplied, and also on the temperature of the escaping flue gases from the boiler furnaces, which should be sufficient to raise the temperature of the water from 75° to 100°, at least. As the economizer is expected to raise the water to a temperature above 212° F., water containing scale-forming impurities should be treated with a solvent that will prevent the deposit of scale on the inner surface of the economizer tubes. As the tubes of the economizer retard the flow of the hot gases, an intense draft is necessary. If natural draft is to be used an extra height should be estimated for when designing the chimney, but with draft induced by mechanical means, such as fans or steam blowers, the required intensity is readily controlled.

**75.** If the economizer raises the temperature of the water from 75° to 100° an increased efficiency of from $7\frac{1}{2}$ to 10 per cent. may be expected. It is not practicable to reduce the temperature of the gases below 250°, and if they do not reach the economizer higher than 350°, the temperature of the feedwater will be raised but 50°, giving an increase of 5 per cent. in efficiency.

The following calculation illustrates the value of an economizer. Assuming that it requires $3\frac{1}{2}$ pounds of coal per hour to generate 1 boiler horsepower, a plant operating 24 hours daily, or 8,760 hours during the year, will require $8,760 \times 3.5 = 30,660$ pounds, or 13.7 tons of coal per horsepower per year, which at $3 per ton will amount to $41.10. Assuming that the economizer saves 8 per cent. of this the saving will be $3.29. The estimated cost of the economizer erected, including by-pass, flues, and dampers, is $1.75 per square foot. Allowing 4 square feet per horsepower, the cost is $7 per horsepower installed. Charging 12 per cent. of the cost against the economizer for attendance, maintenance, depreciation, and interest, we have 84 cents, which amount deducted from saving in coal as above, leaves $2.45 net saving under the above stated conditions. As boiler heating surface costs about 60 cents and upwards per square foot, and economizer heating surface about $1.75 per square foot,

it becomes a nice question to decide wherein lies the more useful and economical investment in heating surface.

**76. Instructions Relating to Economizers.**—Where economizers are used the following instructions relative to their care and management should be observed: The foundations should be substantial. A by-pass flue with dampers must be provided; the flues should have the fewest possible turns, and these should consist of easy curves. Holes, cracks, and air leaks must not be allowed. The main steam-regulated damper should be placed between the economizer and the chimney, and the safety valve should be blown daily or oftener to free any scum collected in the outlet pipe. The blow-off valve should be opened a few seconds daily, as the condition of water may require. All scrapers should be kept well lubricated, and the soot chamber cleaned out frequently. The economizer should be cleaned more or less frequently, according to the quality of the feedwater, to clear the inside of scale and sediment. Thermometers should be fixed in inlet and outlet pipes to determine temperatures.

### HEATERS USED WITH CONDENSING ENGINES

**77.** Steam engines are generally run condensing whenever it is possible to obtain sufficient water. That is, instead of allowing the exhaust steam from the engine cylinder to escape into the air, it is led into a condenser where, by means of cold water, it is condensed, thereby creating a partial vacuum behind the piston, thus practically adding the equivalent pounds pressure represented by the vacuum to the effective steam pressure and effecting a considerable economy.

Heating feedwater where condensing engines are used is a more complicated problem than with simple non-condensing engines. The intermediate feedwater heater connected in the line of exhaust between the engine and the condenser will be beneficial in obtaining heat from the exhaust steam before the steam passes into the condenser; the intermediate heater must be vacuum-tight. The feedwater

passing through this heater will reach from 108° to 110° F. and can then be delivered to an open exhaust-steam heater.

The steam from all pumps, fan engines, and other engines used as auxiliaries is generally not used expansively, and consequently, the temperature of the exhaust steam from these auxiliaries is much higher than from the larger engines. The exhaust from the auxiliary pumps and engines can very profitably be used for further raising the temperature of the feedwater in the open heater from 190° to 210°, thus permitting the delivery of the feedwater to the boilers almost at boiling point. If in addition to this the feedwater is forced through an economizer, the temperature will be raised considerably above the boiling point, and as it enters the boilers the water will be ready to expand into steam at once.

**78.** In a plant where condensers are used, the discharge of condensed steam has the advantage that all of the vegetable and mineral impurities have been removed through evaporation; therefore, if this water is used for boiler feed it is free from these impurities. The disadvantage is the impregnation with cylinder oil, which must be removed before the water is fit for boiler feeding. There are many types of grease extractors and oil separators on the market; the most efficient of these are claimed to remove from 95 to 98 per cent. of the oil contained in the water, thus rendering it sufficiently pure for boiler feed.

## PUMPING

**79.** The cost of pumping water for boiler-feed and condensing purposes in electric power stations is no small item of expense. Every legitimate effort should be made at the time of designing the station to do this work in the most economical manner. The steam consumed by the ordinary steam pump is far beyond what is generally realized, and the subject of steam economy for pumping is most important. It is no uncommon thing to work duplex pumps so that they take steam from seven- to eight-tenths of their stroke,

resulting in an enormous waste of steam. The ordinary steam pump will use 100 to 300 pounds of steam per horsepower per hour.

Several kinds of pumps and injectors are available for forcing the feedwater into the boilers. They may be steam-driven direct-acting, geared from the main engine, or geared to an auxiliary engine. In electric power stations, the pumps are frequently geared to motors that receive their current supply from the main generators. In an injector, the feedwater is forced into the boiler by virtue of the kinetic energy imparted to a jet of water by a jet of steam acting on it. Injectors may be operated either by live steam or by exhaust steam, but the latter cannot be used for forcing against high pressures. The injector is not as reliable as the pump and is not generally used in the regular operation of electric power stations.

Stated in the order of economy of operation, the boiler-feeding appliances would stand as follows:

*Exhaust-steam injectors* feed the boiler up to a pressure not exceeding 75 pounds and heat the feedwater to 185° or 190° with exhaust steam. This is only noted as a method of boiler feed, but is not considered practicable for electric power stations.

A *geared pump run from the engine* derives its power from the most economical source in the station.

A *geared pump driven by an electric motor* derives its power through the generator from the second most economical source.

A *direct-acting pump* with compound steam cylinders, and the exhaust used in an auxiliary heater.

A *direct-acting pump* using steam at high pressure with the exhaust used for heating feedwater in an auxiliary heater.

A *live-steam injector* feeding through a heater.

**80. Pump Governor.**—For best service, the supply of boiler feedwater should be continuous, and regulated by automatic control according to the demands on the boilers. The water-line in the boilers should be maintained at a

constant level. If the level be allowed to fall, the feed will be required more rapidly at intervals, and when so supplied will affect the uniformity of the steam pressure. There are several automatic regulators on the market for this purpose.

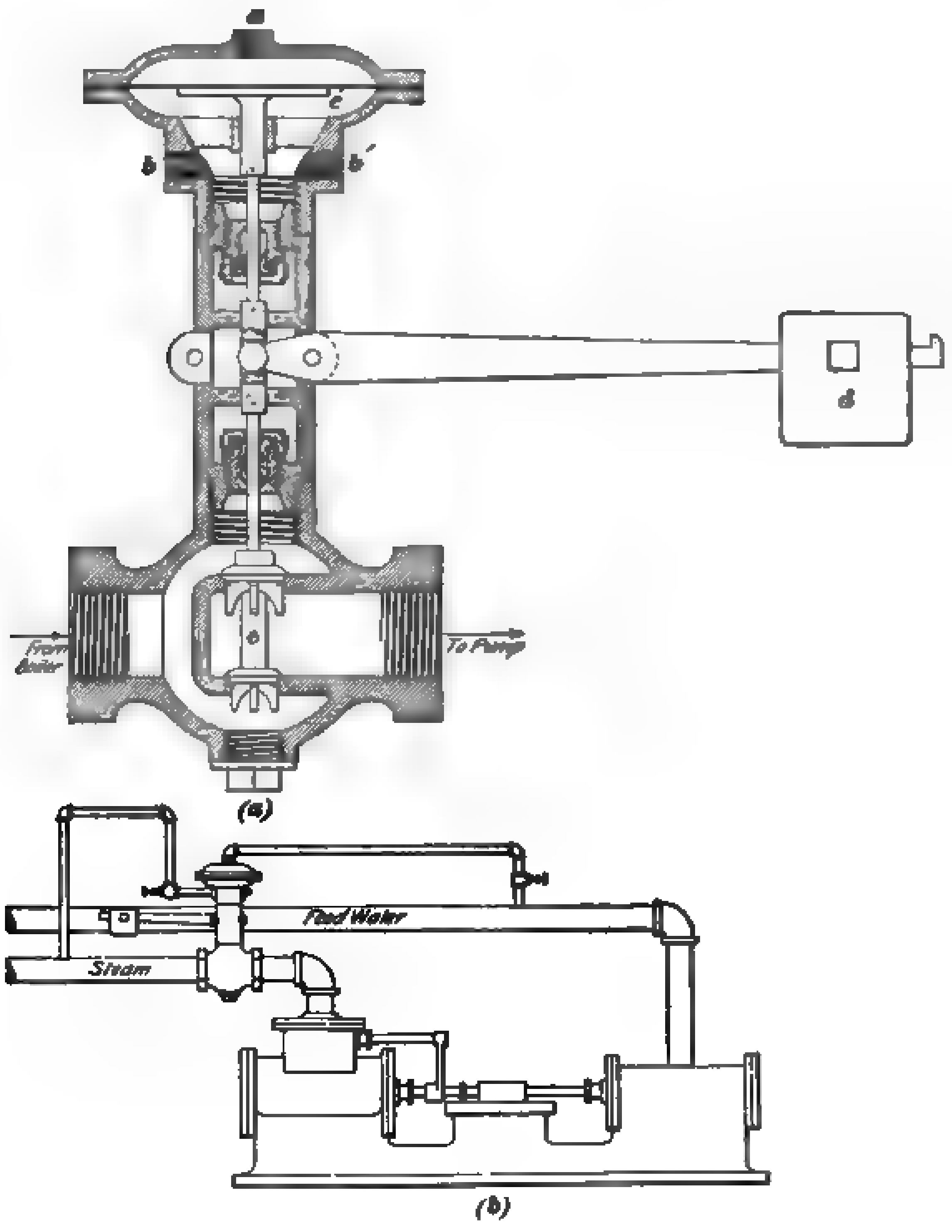


FIG. 21

Fig. 21 illustrates a good device wherein the steam pressure in the boilers is balanced against the water pressure in the feed-line and thus automatic control is obtained. Connection

to the feedwater pipe is made at *a*, Fig. 21 (*a*), and to the steam pipe at *b* or *b'*. The steam is admitted through suitable openings, to the underside of the diaphragm *c* and the water pressure acts on the upper side. By means of the weight *d*, the governor can be adjusted so that when a certain level is maintained the throttle valve *e* will be closed and the pump stopped. Both the upper and lower sides of *c*

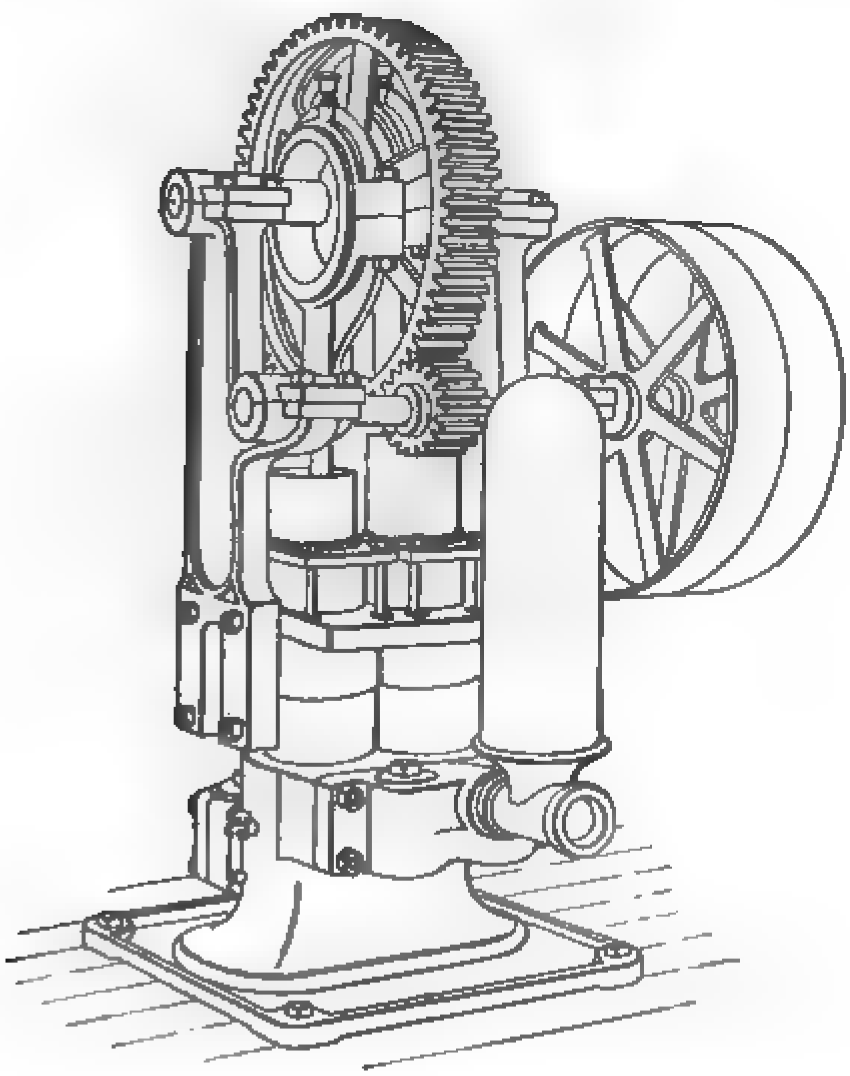

FIG. 22

are connected to the boiler, the upper side connecting to the water space (through the feedpipe) and the lower side to the steam space. A change in water level will therefore affect the resultant pressure on the diaphragm. If the level lowers, the pressure on the upper side becomes less and the steam pressure raises valve *e*, thus starting the pump, which continues to operate until the downward pressure on *c* overcomes

the upward steam pressure and closes the valve *e*, thus stopping the pump. Fig. 21 (*b*) shows the method of piping the governor. Fig. 22 shows a typical **duplex pump** arranged for belt driving from either an engine or an electric motor. Fig. 23 shows a **triplex pump** geared to a motor. **Turbine, or centrifugal,** pumps are well adapted for direct connection to electric motors. Considerable attention has recently been given to the development of this type of pump, and they are now frequently used for power station

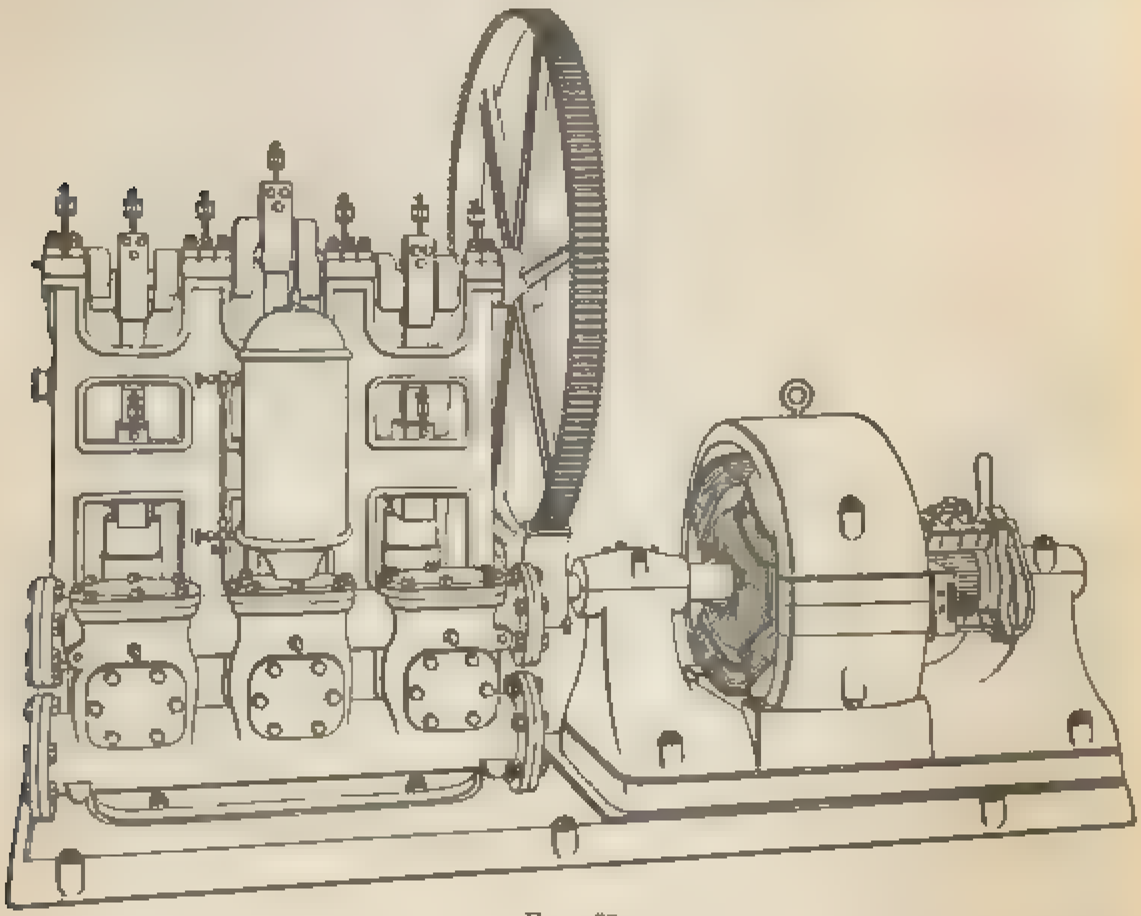

Fig. 23

work. By using two or more pumps in series and thus raising the pressure by two or more stages these pumps can be made to give a good efficiency, and the construction is very simple as compared with a reciprocating pump.

**81. Relative Value of Feeding Methods.** The relative value of injectors, direct acting steam pumps, and pumps driven from the engine, is a question of importance to all steam users. Table VII has been calculated by

D. S. Jacobus, M. E., from data obtained by experiment. It will be noticed that when feeding cold water direct to boilers, the injector has a slightly better economy, but when feeding through a heater, a pump is the most economical.

TABLE VII

RELATIVE ECONOMY OF DIFFERENT METHODS FOR FORCING FEEDWATER INTO BOILERS

| Method of Supplying Feedwater to Boilers | Relative Amount of Coal Required per Unit of Time | Saving of Fuel Over Amount Required When Boiler Is Fed by Direct-Acting Pump Without Heater Per Cent. |
|---|---|---|
| Direct-acting pump feeding water at 60°, without a heater . . . . . . . . . . | 1.000 | .0 |
| Injector feeding water at 150°, without a heater. . | .985 | 1.5 |
| Injector feeding through a heater in which the water is heated from 150° to 200° . . . . . . . . . . . . . | .938 | 6.2 |
| Direct-acting pump feeding water through a heater in which it is heated from 60° to 200° . . . . . . . . | .879 | 12.1 |
| Geared pump, run from the engine, feeding water through a heater in which it is heated from 60° to 200° . . . . . . . . . . . | .868 | 13.2 |

NOTE.—The temperature of the feedwater delivered to the pump or injector is 60° F. The evaporation of the boiler is at the rate of 10 pounds of water from and at 212°, per pound of coal. In this table, the amount of coal per unit of time required by a direct-acting pump feeding water at 60° F., without a heater, is taken as unity.

**82. The Comparative Economy of Motor-Driven Pumps.**—The most desirable and economical type of motor for pump service will probably be a compound-wound double-commutator machine. This combined with series-field commutation can be regulated for at least four speeds, thus giving a practical range of feedwater supply equal to four ranges of piston speed on the usual type of steam pumps. If multi-voltage control is available it also constitutes an excellent method for the control of a pump motor. Other methods of control can also be used, as described in connection with direct-current motors. The efficiency of a small size motor will be 70 to 75 per cent., which is readily obtained in every-day practice. If we assume the average economy of the engine-generator unit to be only .025 electrical horsepower per pound of steam (40 pounds of steam per electrical horsepower per hour), the corresponding economy of the steam pump at 100 pounds of steam per horsepower-hour would be $\frac{40}{100} \times .025 = .01$ horsepower per pound of steam and the motor-driven pump at 70 per cent. efficiency would show an economy of $.025 \times .7 = .0175$ horsepower per pound of steam delivered to the engine, or on the full horsepower-hour basis the steam pump would require 100 pounds and the motor-driven pump $\frac{1}{.0175} = 57$ pounds, the saving by the motor-driven pump being 43 pounds of steam per horsepower-hour.

Assuming the pump to require 5 horsepower on 24 hours daily service, we have $5 \times 24 \times 43 = 5{,}160$ pounds per day, or for 365 days a saving of 1,883,400 pounds of steam. Assuming a good grade of coal and evaporating 6 pounds of water per pound of coal, we have $1{,}883{,}400 \div 6 = 313{,}900$ pounds of coal, or about 140 gross tons, which at $3 per ton would cost $420. This capitalized at 10 per cent. would be $4,200, showing the extra value of the motor-driven pump. In spite, however, of the greater economy of motor-driven pumps, there is considerable difference of opinion as to the advisability of their use. A source of current must

always be available to run the pumps and this means that the generators must either be running or else the station must be equipped with a storage battery. The steam pump is thus more independent than the electrically driven pump and for this reason is often preferred.

# ELECTRIC POWER STATIONS

(PART 2)

## CHIMNEYS AND MECHANICAL DRAFT

### THE COMBUSTION OF FUEL

**1.** In connection with the production of steam, certain salient points regarding the combustion of fuel should be understood. **Fuel** is any substance that, by means of the introduction of natural air, can be burned with economy to generate heat. Each pound of fuel requires a certain quantity of oxygen for its complete combustion, and the amount of air required will vary with the grade of fuel. Each pound of carbon, for its perfect combustion, will, theoretically, require 2.66 pounds of oxygen.

Oxygen is classed as a supporter of combustion, and a **combustible** is a substance capable of rapidly combining with oxygen to produce heat or light.

**2.** Pure air is composed of oxygen, .213 part, and nitrogen, .787 part, or approximately 1 part of oxygen to 4 parts of nitrogen, per unit volume; but the atmosphere is more or less affected by carbonic acid, moisture, and other impurities.

The economic value of fuel is measured by its heating power, which is principally determined by the elements of its composition—carbon, hydrogen, oxygen, nitrogen, water, and ash in the form of non-combustibles. **Combustion** is the chemical union or combination of the constituents of the fuel with the oxygen of the air. Each atom of carbon unites with two atoms of oxygen and during the combination heat is given out.

**3.** Table I shows the proportions of carbon, hydrogen, and oxygen contained in several kinds of fuel, and the pounds of air, theoretically, required for their complete combustion.

Since each pound of carbon requires $2\frac{2}{3}$ pounds of oxygen to burn it to $CO_2$ and air contains 23 per cent. of oxygen, by weight, $2\frac{2}{3} \div .23$ or 11.6 pounds of air is required, theoretically, to burn 1 pound of carbon. The weight of 1 cubic foot of air at sea level is 536 grains, and there are 13.141 cubic feet in 1 pound at atmospheric pressure and 62° F.

TABLE I

AIR REQUIRED FOR COMBUSTION OF FUEL

| Kind of Fuel | Proportional Weight of Given Constituents per Unit Weight of Coal | | | Pounds of Air Required per Pound of Fuel |
|---|---|---|---|---|
| | Carbon | Hydrogen | Oxygen | |
| Charcoal . . . . . | .93 | | | 11.60 |
| Coke . . . . . . . | .94 | | | 11.28 |
| Coal, anthracite | .92 | .035 | .026 | 12.13 |
| Coal, bituminous | .87 | .05 | .04 | 12.06 |
| Coal, coking . . . | .85 | .05 | .06 | 11.73 |
| Coal, cannel . . . | .84 | .06 | .08 | 11.88 |
| Coal, lignite . . . | .70 | .05 | .20 | 9.30 |
| Wood, dry . . . . | .50 | .06 | .31 | 7.68 |
| Petroleum oil . . | .85 | | | 15.65 |

**4.** The amount of air, theoretically, required for perfect combustion of fuel is not attained in practice. Experiments have shown that from 48 to 70 per cent. of air in excess of the theoretical quantity is required with natural draft, while from 20 to 30 per cent. excess is required with forced or mechanical draft. Because of the size of the coal and its arrangement on the fire, the passage of the air through it is more or less restricted, and in practice it usually becomes

necessary to supply air in excess of the amount theoretically calculated to insure complete combustion.

**5.** Coal, in burning, combines with the oxygen of the air, giving up its carbon; first, to form carbonic oxide, or carbon monoxide $CO$, and further combining with oxygen to form $CO_2$, carbonic acid or carbon dioxide, the presence of which indicates complete combustion. The carbonic oxide in uniting with oxygen gives up one-third more energy than if passed out as carbonic oxide, and the condition of combustion is indicated by the percentage of carbonic oxide that exists in the gas leaving the furnace; a large percentage of carbonic oxide indicates that the combustion is incomplete. Insufficient air supply, or incomplete combustion of the coal will change the ratio of carbonic oxide to carbonic acid in the gas issuing from the boiler.

The average amount of air required for the combustion of 1 pound of coal is 21 pounds, or 276 cubic feet, at 62° F. To deliver this immense quantity of air in a manner such that it can be properly utilized, it becomes necessary to provide either *chimneys* or *mechanical draft*. A very brief calculation will serve to impress strongly on the memory the magnitude of the work required and the vast quantity of air to be moved. Take 50 square feet of grate surface on which 25 pounds of coal is burned per square foot per hour; we then have $50 \times 25 \times 276 = 345{,}000$ cubic feet of air to be moved per hour to facilitate the burning of 1,250 pounds of coal. To secure the rapid and almost automatic movement of this large volume of air, it is evident that intensity of draft is required.

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## DRAFT

**6. Definition.**—As the term *draft pressure* is usually employed, it refers to the difference in weight between the column of hot air or gas in the chimney, and a column of cold air outside, of the same height and area. The intensity, or force, of the draft, which is the velocity imparted to the movement of the air, is measured in inches of water

by a **draft gauge.** This instrument, illustrated in Fig. 1, is a U-shaped tube partially filled with water. One end is open to the atmosphere and the other end is connected with the flue or chimney of which it is desired to measure the draft pressure. The liquid rises in one arm and lowers in the other arm of the gauge; the pressure of the external air pushes the water up in the arm connected to the chimney until the difference between the levels *H* and *Z* is sufficient to balance the difference in pressure between the flue and the atmosphere, and represents the height of a column of the liquid that will be sustained by the excess of pressure. The difference between the levels *H* and *Z* can be read off by means of the scale and the intensity of the draft is expressed in inches of water.

Fig. 1

**Draft** must be expended in two ways: First, to impart the necessary velocity to a sufficient volume of air for the direct purpose of combustion, and second, to overcome all resistance offered to the air in its passage through the grate, fuel, flue passages, and chimney. The velocity increases as the square root of the pressure, or intensity.

## CHIMNEYS

**7.** The purpose of the **chimney** is, first, to produce a draft of sufficient intensity to facilitate combustion, and second, to carry the obnoxious products of combustion to such an elevation as will make them unobjectionable. In designing a chimney, sufficient height must be given to obtain the required intensity of draft, and sufficient area to pass freely the products of combustion.

**8.** The numerous rules that have been formulated to determine the area and height of chimneys differ more or less, and while such rules may serve somewhat as a guide, the proportioning becomes very largely a matter of judgment gained from experience. The best practice and

judgment, backed by experience, will always decide in favor of the taller chimney, particularly keeping in mind the inevitable future increase of boiler capacity. As the number of boilers served by the chimney increases, the height will increase in greater ratio than the area of the chimney, because greater intensity will be required to overcome the friction in the flue connections between the boilers and the stack.

The horsepower capacity of the boiler plant will also be a guide to the height of the chimney. On this basis the height should be about as follows: Up to 250 horsepower, not less than 100 feet high; from 250 to 500 horsepower, 110 to 130 feet; from 500 to 2,000 horsepower, 130 to 150 feet. These heights are irrespective of the kind of coal to be used.

### TABLE II

SIZE OF CHIMNEYS WITH APPROXIMATE HORSEPOWER OF BOILERS

| Diameter Inches | Height of Chimneys and Commercial Horsepower | | | | | | Effective Area Square Feet | Actual Area Square Feet |
|---|---|---|---|---|---|---|---|---|
| | 100 | 110 | 125 | 150 | 175 | 200 | | |
| 36 | 182 | | | | | | 5.47 | 7.07 |
| 39 | 219 | | | | | | 6.57 | 8.30 |
| 42 | 258 | 271 | | | | | 7.76 | 9.62 |
| 48 | 348 | 365 | 389 | | | | 10.44 | 12.57 |
| 54 | 449 | 472 | 503 | 551 | | | 13.51 | 15.90 |
| 60 | 565 | 593 | 632 | 692 | 748 | | 16.98 | 19.64 |
| 66 | 694 | 728 | 776 | 849 | 918 | 981 | 20.83 | 23.76 |
| 72 | 835 | 876 | 934 | 1,023 | 1,105 | 1,181 | 25.08 | 28.27 |
| 78 | | 1,038 | 1,107 | 1,212 | 1,310 | 1,400 | 29.73 | 33.18 |
| 84 | | 1,214 | 1,294 | 1,418 | 1,531 | 1,637 | 34.76 | 38.48 |
| 90 | | | 1,496 | 1,639 | 1,770 | 1,893 | 40.19 | 44.18 |
| 96 | | | | 1,876 | 2,027 | 2,167 | 46.01 | 50.27 |

**9.** Table II gives the relation between the diameter and height of chimneys and the boiler capacity, in commercial

horsepower. The figures at the head of the columns represent different heights of chimneys, in feet, while those in the left-hand column represent the diameter, in inches, the flue in the chimney being circular in cross-section. The two right-hand columns give the effective area of flue, in square feet, and the actual area, in square feet. The effective area is always less than the actual area because the air next the wall of the flue is retarded by friction and the whole area of cross-section is not, therefore, equally effective in allowing the draft to pass up the chimney. In Table II, a chimney 42 inches in diameter and 110 feet high will be capable of supplying draft for 271 horsepower of boiler capacity. The actual area of cross-section of the flue will be 9.62 square feet, but, allowing for friction, the effective area is reduced to 7.76 square feet.

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## FUEL BURNED PER SQUARE FOOT OF GRATE SURFACE

**10.** Modern practice has increased the amount of fuel burned per square foot of grate surface per hour until 25 pounds per square foot is quite common, and 30 to 35 is attained at times under maximum overload. The kind of coal to be burned must be considered, as well as the possibility of change at some future time from one kind to another for commercial reasons. The following heights of chimneys are recommended as the least to be used with the coals mentioned: 100 feet for burning bituminous slack, 120 feet for slow-burning bituminous, 130 feet for anthracite pea, 150 feet for anthracite buckwheat. The rate of combustion that can be obtained in any given case will depend on the draft pressure, and this in turn depends on the height of the chimney. Table III shows the combustion that is possible per square foot of grate surface with various heights of chimneys and corresponding draft pressures.

The designer should anticipate the future increase in the cost of coal, and the necessity of burning lower-grade coal,

TABLE III

RATE OF COMBUSTION FOR DIFFERENT TOTAL DRAFT PRESSURES

| Height of Chimney Above Grate Feet | Total Draft Pressure Inches of Water | Rate of Combustion per Square Foot of Grate Pounds per Hour |
|---|---|---|
| 100 | .729 | 22 |
| 110 | .802 | 24 |
| 120 | .875 | 27 |
| 130 | .948 | 30 |
| 140 | 1.029 | 34 |
| 150 | 1.095 | 40 |
| 180 | 1.313 | 50 |
| 200 | 1.459 | 60 |
| 225 | 1.641 | 70 |
| 250 | 1.825 | 80 |
| 300 | 2.189 | 90 |

and will therefore be justified in providing a strong, intense draft; he must also provide for increase of boiler capacity.

Where economizers are used in connection with natural draft, as illustrated later in connection with Fig. 5, the importance of sufficient intensity of draft to overcome the resistance through the economizers becomes evident. This must be taken into account when determining the height of chimney.

RULES RELATING TO CHIMNEYS

**11.** The capacity of the chimney will vary as the square root of the height; and the capacity also varies directly as the area. For example, in a chimney 160 feet high, the velocity will be, theoretically, twice that in a 40-foot chimney and should discharge twice the amount of gas in a given time, or if the cross-section is twice as great, a similar result will be obtained. In calculating the area of a chimney the volume of the escaping gas must be duly considered according to the composition of the coal.

**12. Rule for Finding the Cross-Sectional Area of Chimneys.**—On the basis that the ordinary horsepower will require the burning of an average of 5 pounds of coal per hour, the following rule, due to Kent, will be of service for calculating the cross-sectional area of chimneys. This gives a liberal allowance because with first-class installations the coal consumption would not be as great as 5 pounds per horsepower per hour. The large allowance is made to cover the use of poor coal or the forcing of the boilers on account of overloads.

**Rule.**—*Divide the horsepower by 3.33 times the square root of the height. The quotient will be the required effective area, in square feet. To the diameter so found add 4 inches to compensate for friction.*

Example.—What should be the diameter of a chimney 150 feet high to carry off the gases from boilers of 300 horsepower capacity?

Solution.—From the above rule, effective area, in square feet, $= \frac{300}{3.33 \times \sqrt{150}} = \frac{300}{3.33 \times 12.25} = 7.35$. This corresponds to an effective diameter of 3.06 ft. (or about 3 ft. ¾ in.), nearly. To this must be added 4 in. to allow for friction so that the actual inside diameter will be about 3 ft. 4¾ in. Ans.

**13. Relation Between Draft and Temperature of Gases.**—In the diagram, Fig. 2, curve $B$ shows the draft (inches of water) for a chimney 100 feet high where the

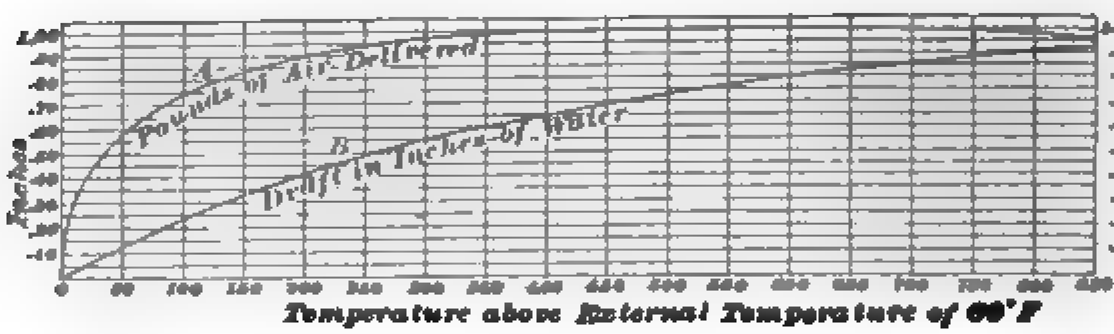



Fig. 2

temperature of the products of combustion varies from 0° to 850° above the assumed external atmospheric temperature of 60° F. Each division of the vertical scale represents $\frac{1}{50}$ inch. Curve $A$ shows the relative quantity, pounds of

air, that would be delivered at the various temperatures. If, for example, the quantity of air at 100° were represented by .75, the quantity at 200° would be represented by .90.

EXAMPLE 1.—If a stack is capable of discharging 12,000 pounds of air per hour when the difference between the temperature of the gases supplied to the stack and the outside temperature at 60° is 250°, what amount can it discharge if the difference is 375°?

SOLUTION.—Fig. 2 shows that for a difference in temperature of 250° the ordinate of the curve *A* showing the relative weights of air delivered is .95. For a difference in temperature of 350° the ordinate is 1, hence the weight delivered in the second case will be $12{,}000 \times \frac{1}{.95} = 12{,}630$ lb., approximately. Ans.

The importance of keeping the escaping gases down to 350° to 450° F., as indicated in this diagram, will be readily appreciated, as no practical gain in draft is effected under the specified conditions by carrying the temperature in the chimney more than 400° F. above the atmospheric temperature of 60° F. It will be noted that practically no increase in the pounds of air is carried through the chimney, at any temperature above 410° F. This fact should be carefully fixed in mind in connection with proportions and setting of boilers, and the use of fuel economizers.

**Rule.**—*To determine the quantity of air, in pounds, that a given chimney will carry per hour, multiply the ordinate for curve A at a given temperature on the diagram, Fig. 2, by 1,000 times the effective area, in square feet, and by the square root of the height, in feet.*

EXAMPLE 2.—How many pounds of air will be carried per hour by a chimney 150 feet high and having an effective area of 20 square feet? The temperature of the gases is 250° above the outside temperature of 60°.

SOLUTION.—From Fig. 2, the ordinate of curve *A* corresponding to 250 is .95 inch, hence, applying the rule, we have

$$\text{air carried} = .95 \times 1{,}000 \times 20 \times \sqrt{150} = 232{,}693 \text{ lb. Ans.}$$

This rule gives the maximum capacity of the chimney, and allowance must be made for friction through all flue and draft connections between the furnace and the chimney.

### FORMS OF CHIMNEY

**14. Round Versus Square Chimneys.**—Practice has shown that the **round chimney** has several advantages over the **square chimney.** Externally, a round chimney offers least resistance to wind pressure, the **octagonal** shape is next desirable on this account, and the square chimney offers greatest resistance. Internally, the round flue offers less resistance and gives a more effective draft than the square flue, the corners of which are filled with eddy currents and are not effective for carrying away the products of combustion.

**15. Types of Construction.**—Four types of chimney construction may be considered briefly as follows: The chimney of least cost can be constructed of steel plates riveted together, not lined with brick; it can be supported on a breeching, or flue connections of the boilers, or on an independent foundation, and must be secured in true perpendicular position by guy rods suitably anchored. The next advance beyond this type of cheap chimney would be the self-supporting steel-plate chimney secured with anchor bolts to a foundation of sufficient weight and area to afford the necessary stability to withstand all strains due to wind pressure. The next type of construction is a steel-plate chimney similar to this and lined with brick for a portion of the height. The durability of steel-plate chimneys depends on the thickness of the metal, the kind of fuel burned in the furnaces, the atmospheric conditions surrounding the location, and the care taken to maintain the chimney in good condition. This last requires that the chimney shall be frequently painted with a good quality of paint. The annual cost of maintenance can here be considered as offsetting the interest charge on the higher cost of a brick chimney. The next in order is the chimney constructed of selected hard brick, having an external wall and an internal wall forming the core of the chimney, and so constructed that the core is free to expand or contract without strain on the external wall. Square chimneys, being undesirable, will not be considered.

**16.** The octagonal chimney can be built at as low a cost as the square chimney, is more attractive in design, and offers less resistance to wind pressure. The round core may be easily constructed in the octagonal chimney. Fig. 3 shows a section of a round chimney with core, and Table IV, in combination with Fig. 3, gives data on chimney construction. This table shows the dimensions of various chimneys varying from 34 inches flue diameter and 70 feet in height to 92 inches diameter and 125 feet in height. The vertical dimensions in Fig. 3 are for a 125-foot chimney.

Another type of chimney largely used in European countries, and also becoming popular in the United States, is the *Custodis chimney*, of especially molded and perforated radial brick. These chimneys are neat in design, effective in service, very substantial in their methods of construction, and do not require an internal core or flue. They have

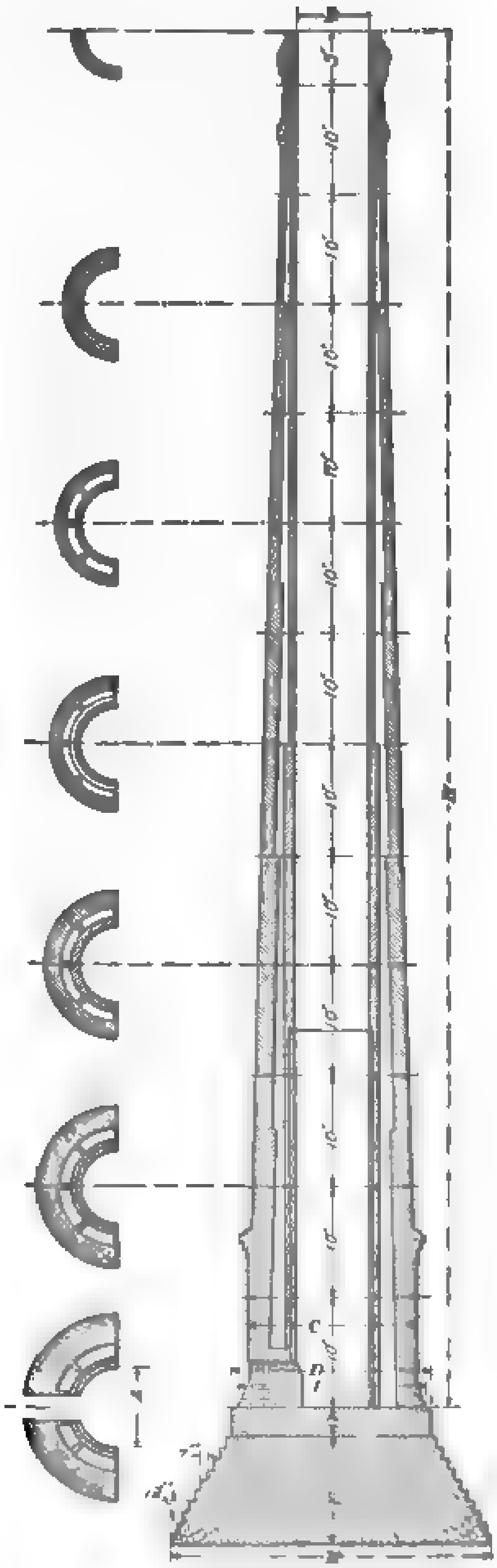


FIG. 3

## TABLE IV
### DIMENSIONS OF CHIMNEYS

| Horsepower | A | B | C | | D | | H | Chimney | | | | | | Flue | | | | Total Number of Bricks | Number of Firebricks | Approximate Depth of Foundation | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 20-Inch Wall | 16-Inch Wall | 12-Inch Wall | 8-Inch Wall | 4-Inch Wall | Half Batter | 8-Inch Wall | 4-Inch Wall | Height of Firebrick | Half Batter | | | | |
| | In. | In. | Ft. | In. | Ft. | In. | Ft. | Ft. | Ft. | Ft. | Ft. | Ft. | In. | Ft. | Ft. | Ft. | In. | | | Ft. | In. |
| 100 | 34 | 41 | 7 | 8 | 8 | 8 | 70 | | | | 30 | 40 | 2.5 | | 70 | 20 | .5 | 17,000 | 1,150 | 8 | |
| 132 | 38 | 45 | 8 | | 9 | | 70 | | | | 30 | 40 | 2.5 | | 70 | 20 | .5 | 18,000 | 1,275 | 8 | |
| 168 | 40 | 48 | 8 | 8 | 9 | 8 | 80 | | | | 40 | 40 | 2.5 | | 80 | 20 | .5 | 23,000 | 1,350 | 8 | |
| 200 | 44 | 52 | 9 | | 10 | | 80 | | | | 40 | 40 | 2.5 | | 80 | 20 | .5 | 24,000 | 1,475 | 8 | |
| 264 | 46 | 54.5 | 9 | 5 | 10 | 5 | 85 | | | 25 | 25 | 35 | 2.5 | 25 | 60 | 25 | .5 | 32,000 | 1,900 | 8 | 6 |
| 336 | 50 | 58.5 | 9 | 9 | 10 | 9 | 85 | | | 25 | 25 | 35 | 2.5 | 25 | 60 | 25 | .5 | 33,000 | 2,075 | 8 | 6 |
| 400 | 54 | 63 | 10 | 4 | 11 | 4 | 90 | | | 30 | 30 | 30 | 2.5 | 25 | 65 | 25 | .5 | 39,000 | 2,225 | 8 | 6 |
| 450 | 58 | 67 | 10 | 8 | 11 | 8 | 90 | | | 30 | 30 | 30 | 2.5 | 25 | 65 | 25 | .5 | 41,000 | 2,400 | 8 | 6 |
| 500 | 60 | 69.5 | 11 | 1 | 12 | 1 | 95 | | | 30 | 30 | 35 | 2.5 | 25 | 70 | 25 | .5 | 45,800 | 2,475 | 9 | |
| 550 | 62 | 71.5 | 11 | 3 | 12 | 3 | 95 | | | 30 | 30 | 35 | 2.5 | 25 | 70 | 25 | .5 | 47,200 | 2,550 | 9 | |
| 600 | 64 | 73.5 | 11 | 5 | 12 | 5 | 95 | | | 30 | 30 | 35 | 2.5 | 25 | 70 | 25 | .5 | 48,600 | 2,625 | 9 | |
| 650 | 66 | 75.5 | 11 | 7 | 12 | 7 | 95 | | | 30 | 30 | 35 | 2.5 | 25 | 70 | 25 | .5 | 50,000 | 2,700 | 9 | |
| 700 | 68 | 78 | 12 | 5.5 | 13 | 7 | 100 | | 25 | 25 | 25 | 25 | 2.2 | 30 | 70 | 30 | .5 | 63,000 | 3,475 | 9 | 6 |
| 750 | 70 | 80 | 12 | 7.5 | 13 | 9 | 100 | | 25 | 25 | 25 | 25 | 2.2 | 30 | 70 | 30 | .5 | 64,500 | 3,550 | 9 | 6 |
| 800 | 72 | 82 | 12 | 9.5 | 13 | 11 | 100 | | 25 | 25 | 25 | 25 | 2.2 | 30 | 70 | 30 | .5 | 66,000 | 3,625 | 10 | |
| 850 | 74 | 84 | 12 | 11.5 | 14 | 2 | 100 | | 25 | 25 | 25 | 25 | 2.2 | 30 | 70 | 30 | .5 | 67,500 | 3,700 | 10 | |
| 900 | 76 | 87 | 13 | 4 | 14 | 6 | 110 | | 25 | 25 | 25 | 35 | 2.2 | 35 | 75 | 30 | .5 | 72,000 | 3,800 | 10 | 6 |
| 950 | 78 | 89 | 13 | 6 | 14 | 8 | 110 | | 25 | 25 | 25 | 35 | 2.2 | 35 | 75 | 30 | .5 | 74,000 | 3,900 | 10 | 6 |
| 1,000 | 80 | 91 | 13 | 8 | 14 | 10 | 110 | | 25 | 25 | 25 | 35 | 2.2 | 35 | 75 | 30 | .5 | 76,000 | 4,000 | 11 | |
| 1,100 | 84 | 95 | 14 | | 15 | 2 | 110 | | 25 | 25 | 25 | 35 | 2.2 | 35 | 75 | 30 | .5 | 79,000 | 4,200 | 11 | |
| 1,200 | 86 | 98.5 | 14 | 6 | 16 | | 125 | 25 | 25 | 25 | 25 | 25 | 2.2 | 60 | 65 | 35 | .5 | 108,000 | 5,000 | 12 | |
| 1,300 | 88 | 100.5 | 14 | 8 | 16 | 2 | 125 | 25 | 25 | 25 | 25 | 25 | 2.2 | 60 | 65 | 35 | .5 | 111,000 | 5,100 | 12 | |
| 1,400 | 90 | 102.5 | 14 | 10 | 16 | 4 | 125 | 25 | 25 | 25 | 25 | 25 | 2.2 | 60 | 65 | 35 | .5 | 114,000 | 5,200 | 12 | |
| 1,500 | 92 | 104.5 | 15 | | 16 | 6 | 125 | 25 | 25 | 25 | 25 | 25 | 2.2 | 60 | 65 | 35 | .5 | 117,000 | 5,300 | 12 | |

been used for many of the most modern power stations of large size.

Fig. 4 shows the method of construction used in the Custodis chimneys. A number of different sizes of hard-burned radial brick are used, these bricks being perforated as shown. The perforations allow the bricks to be burned hard and uniform and also insure tight and well-locked joints, since the mortar is worked into the perforations about ½ inch. The perforated bricks are considerably larger than ordinary bricks and the number of mortar joints in a chimney is thus reduced.

All brick chimneys should be finished with a cast-iron cap, well anchored in place, and fitted with a lightning rod substantially erected and thoroughly grounded. An iron ladder should be built in the brickwork to give access to the top.

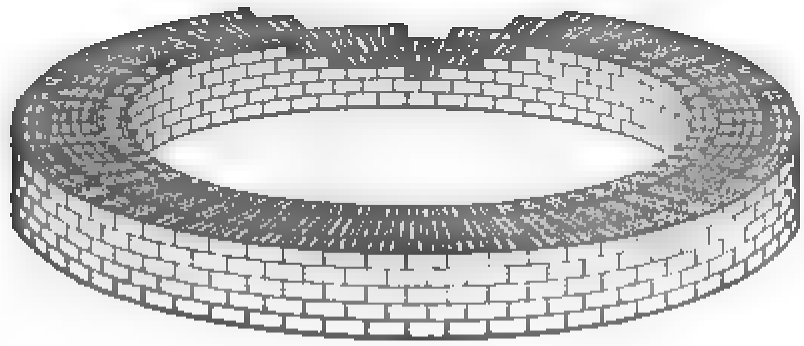
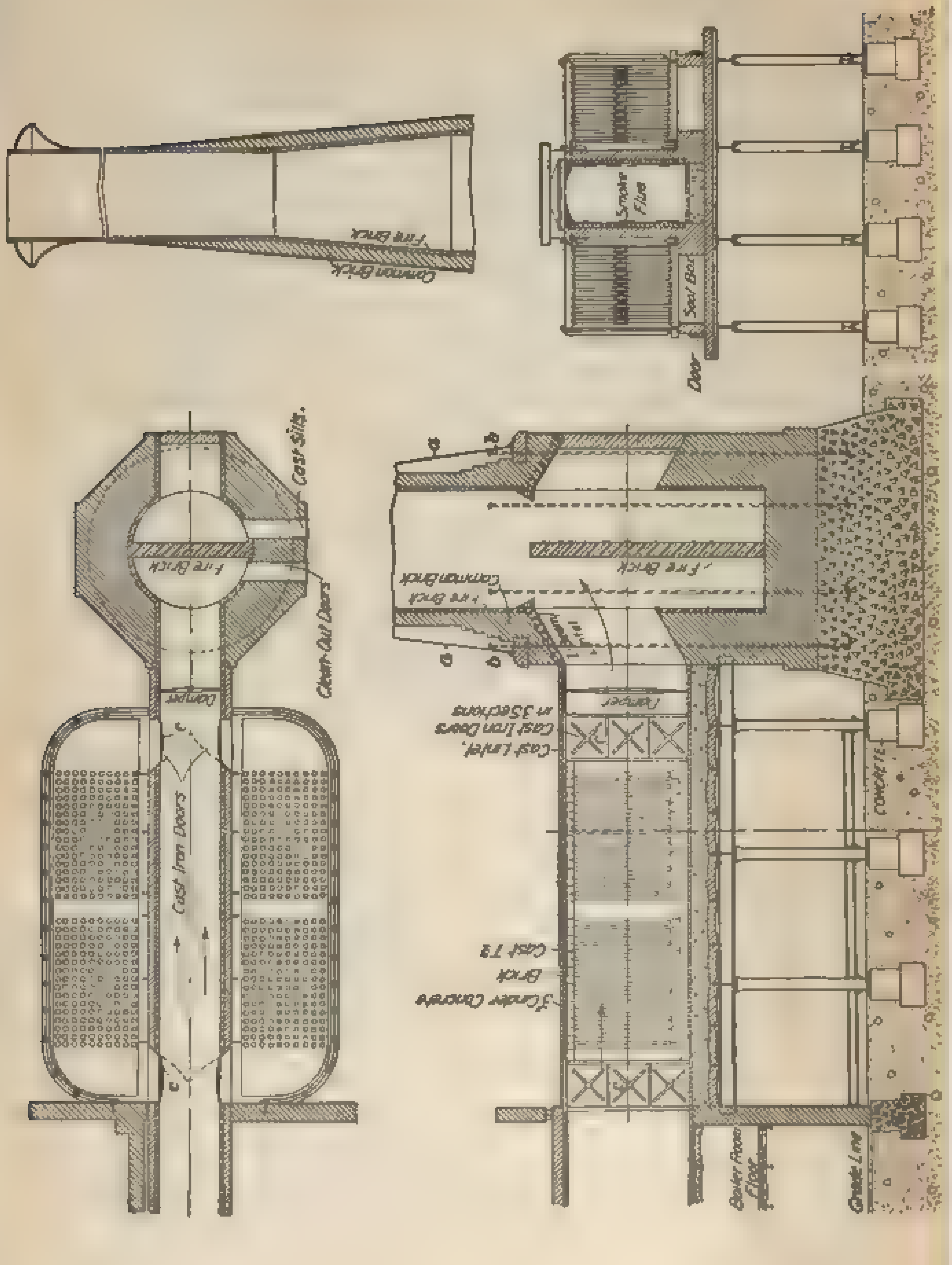


Fig. 4

**17.** Fig. 5 illustrates the construction of a brick-lined steel stack supported on an octagonal brick foundation. The outer steel-plate shell *a* is anchored to the foundation by means of eight foundation bolts *b*. The stack is lined with both common brick and firebrick, as shown. In many cases the firebrick is not carried more than one-half or two-thirds the height of the chimney, the balance being lined with a good quality of hard-burned brick. Fig. 5 also shows a method of arranging the economizer. The gases on their way from the boiler to the stack can be made to take the path through the economizer by opening the cast-iron doors *c* shown in the figure, or these doors can be closed and the gases allowed to pass through the central smoke flue, as indicated by the full-line arrows.


Fire Brick
Common Brick
Smoke Flue
Soot Box
Door
Cast Sills
Fire Brick
Clean-Out Doors
Damper
Cast Iron Doors
Common Brick
Fire Brick
Damper
Cast Lintel,
Cast Iron Doors
in 3 Sections
Cast T's
Brick
Cinder Concrete
Concrete
Boiler Room Floor
Grade Line

### STRENGTH OF CHIMNEYS

**18.** As chimneys must successfully withstand pressure in a heavy storm, the material employed and the construction adopted must give solidity and strength to a sufficient extent to withstand a strong pressure per square foot concentrated entirely on one side. A summary of the records and reports from the various observatories shows that the wind pressure may vary from 1 pound per square foot in a gentle breeze, to 50 pounds per square foot in a strong hurricane blowing at the rate of 100 miles per hour. The stability and power to withstand the pressure of high wind requires a proportionate relation between the weight, height, breadth of base, and exposed area of the chimney. For a square chimney the total weight should be fifty-six times the breadth of base multiplied by the exposed area; for an octagonal chimney it should be thirty-five times, and for a circular chimney twenty-eight times. For example, suppose that a square chimney is 100 feet high and has an average breadth of 8 feet; the area of a side exposed to the wind is then $100 \times 8$. If the breadth of base is 10 feet, the total weight, in order to secure stability, should be $56 \times 10 \times 100 \times 8 = 448{,}000$ pounds. Brickwork weighs from 100 to 130 pounds per cubic foot, hence such a chimney must average 13 inches in thickness in order to be safe. A round stack may weigh half the above amount or have less base. The breadth of base of chimneys is ordinarily made one-tenth the height, and great care should be taken to see that a substantial foundation is provided.

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### MECHANICAL DRAFT

**19. Mechanical draft** is any system whereby artificial draft is created, and may be either *forced* or *induced*. In laying out an electric power station, the question comes up as to whether natural or mechanical draft will most effectively and efficiently secure the desired result. All valuable points of each should receive due consideration, it being understood that when desired, economizers can be used with either

system. The essential feature is sufficient intensity of draft; this is a most important factor, and must be under good control.

---

FORCED DRAFT

**20. Fans.**—**Forced draft** may be produced by several methods. One method is to close the ash-pits tightly and use fans for forcing the air blast under the grate, as shown in Fig. 6. The air from the blower *a*, driven by the small steam engine *b*, is introduced by leading a duct into the bridge wall *c* under the grates. The distribution of air is controlled by means of dampers or deflecting plates, so

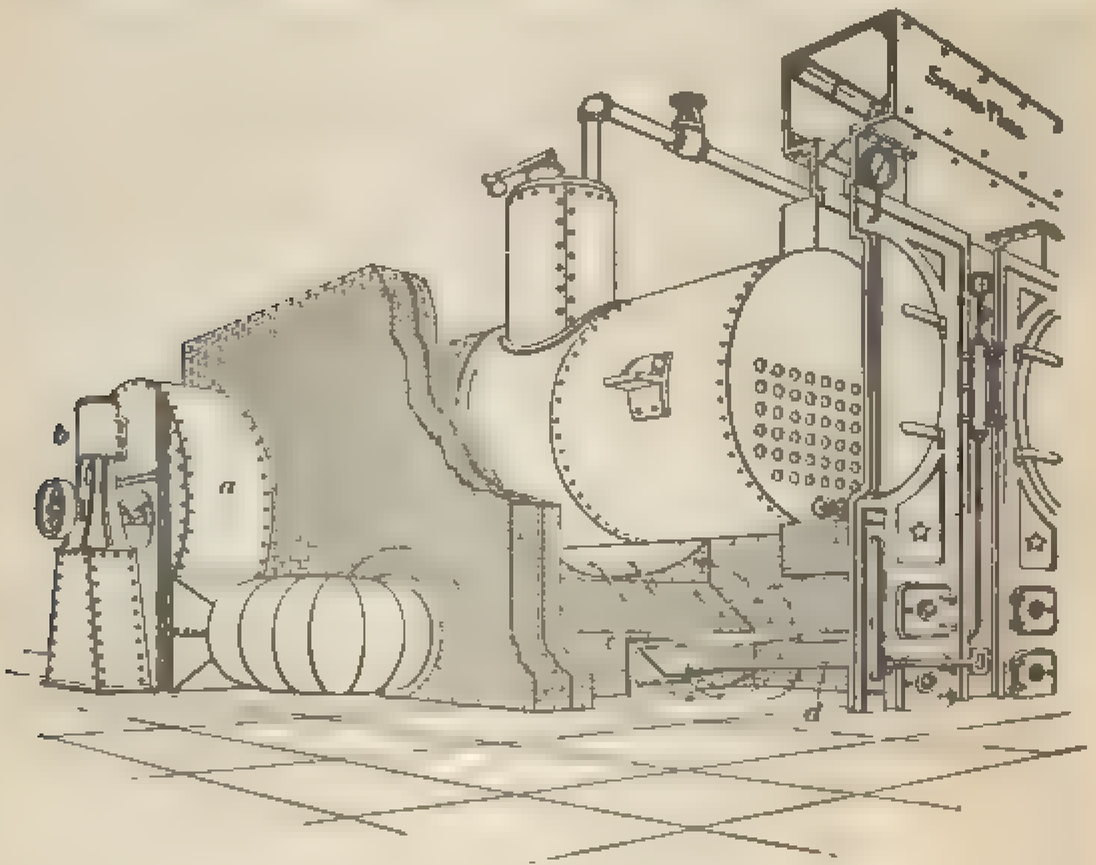

FIG. 6

arranged as to send the air to all parts of the ash-pit, and regulated by means of a rod *d* reaching through the front of the boiler.

**21.** Another method is to build an air duct under the floor in front of the boilers and introduce the air through suitable passages to the ash-pit in the front, controlling with dampers regulated by means of hand rods, as above

mentioned. This method will be understood by referring to Figs. 7 and 8. This air-blast method is not desirable for continuous service, but in connection with chimney draft is very advantageous as an auxiliary to increase the steaming

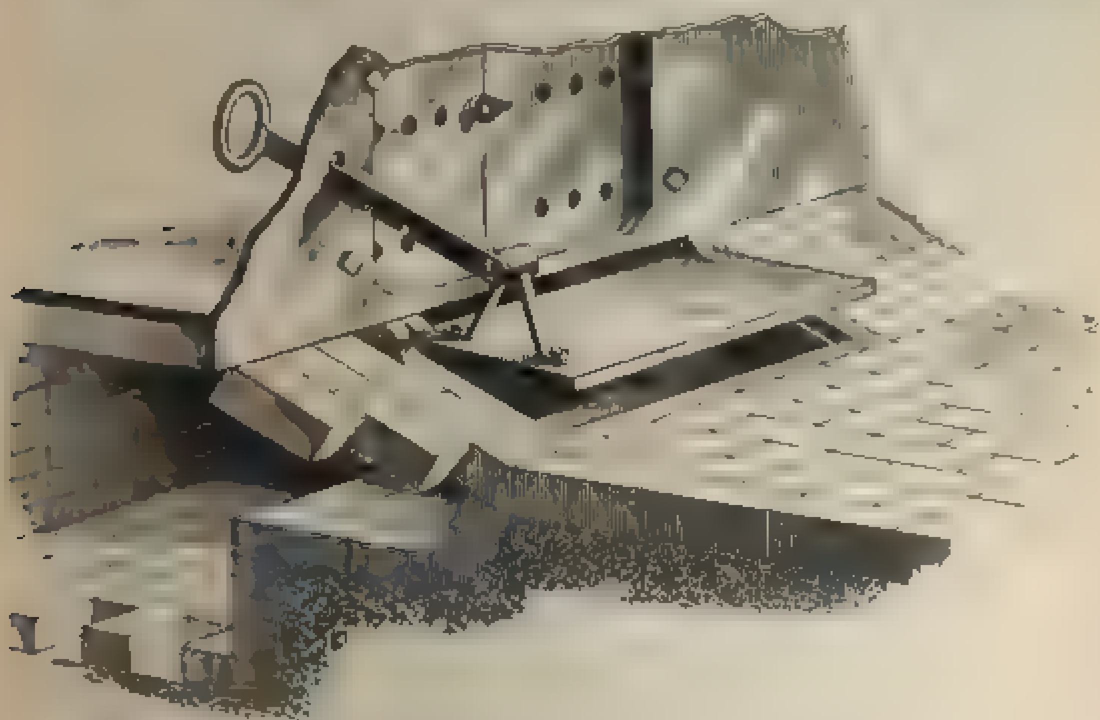

FIG. 7

capacity of the boilers and to aid in carrying heavy peak loads for a few hours.

**22. McClave Argand Steam Blower.**—Another method of producing a forced draft is by means of the McClave

FIG. 8

**Argand steam blower,** illustrated in Fig. 9. This is an effective device for producing a forced draft for burning low grades of anthracite or bituminous coal. It consists of an air tube *t* discharging from the end *s* below the grate. In the other

end of the tube is placed a ring-shaped tube *r* perforated on the right with small holes. Steam from the boiler is led into the ring by the pipe *l* and escapes in jet through the perforations, carrying air with it into the ash-pit. A small amount of steam is thus thoroughly mixed with a large volume of air and delivered under the grates at such a pressure as to augment materially the effect of the natural draft. Each blower has the advantage of independent regulation instead of relying on a single fan delivering air through a conduit to a number of boilers. The combination of steam and air is

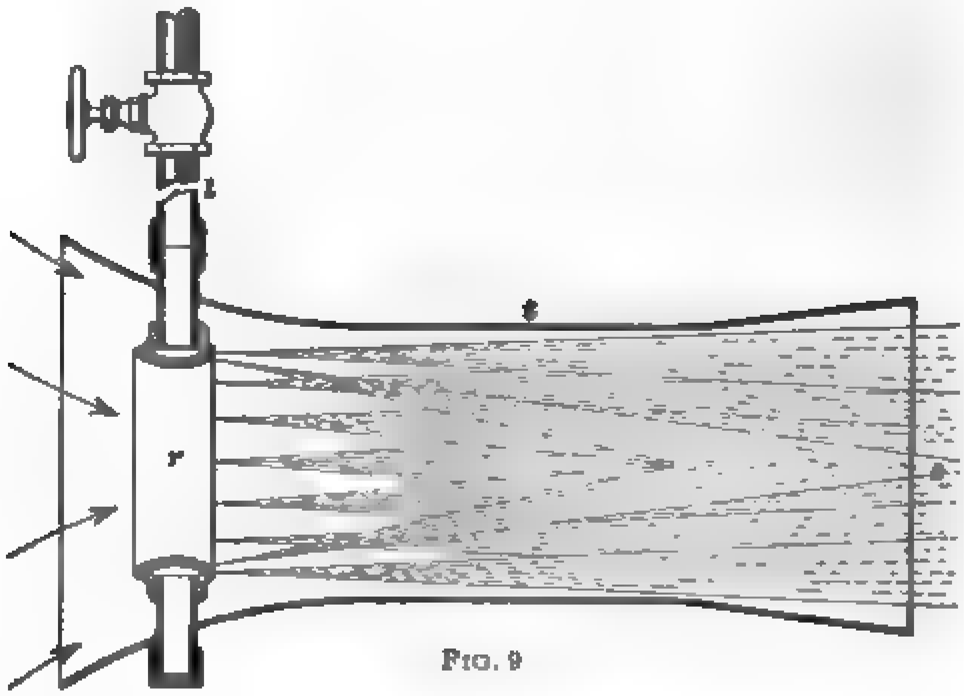

FIG. 9

beneficial in securing more perfect combustion of the low-grade fuels and reducing the hardness of the clinkers. This method is good for burning low-grade anthracite, but cannot be recommended for general use.

Steam jets may be used directly under the grates as an auxiliary in conjunction with natural draft. This plan has nothing to recommend it for adoption in a new plant, and is simply a poor makeshift to tide over an emergency in helping out poor chimney draft.

**23. Enclosed Fireroom Method.**—The enclosed fireroom method, as applied in some steamships, is so arranged that the air in the fireroom is maintained under pressure

by powerful blowers, and the boilers can be worked with ash-pit doors open; an air pressure of 1 inch will afford an intense draft. This method is not practicable for power stations.

### ADVANTAGES AND DISADVANTAGES OF FORCED DRAFT

**24.** The several methods of forced draft give good results under favorable conditions, but the following disadvantages are to a greater or less degree always present. Soot and ashes accumulate rapidly on the heating surface of the boilers; there is a tendency for the fires to burn unevenly; when firing, the soot, ashes, and gas blow into the face of the fireman, unless the draft is cut off or the gases pass out through the chimney; ashes cannot conveniently be removed without shutting off the draft.

Forced-draft methods may frequently be applied to boilers already in use, and thus increase their evaporative capacity, also making it possible to burn a cheaper grade of fuel than was originally intended, and thereby compensating in a measure for these disadvantages.

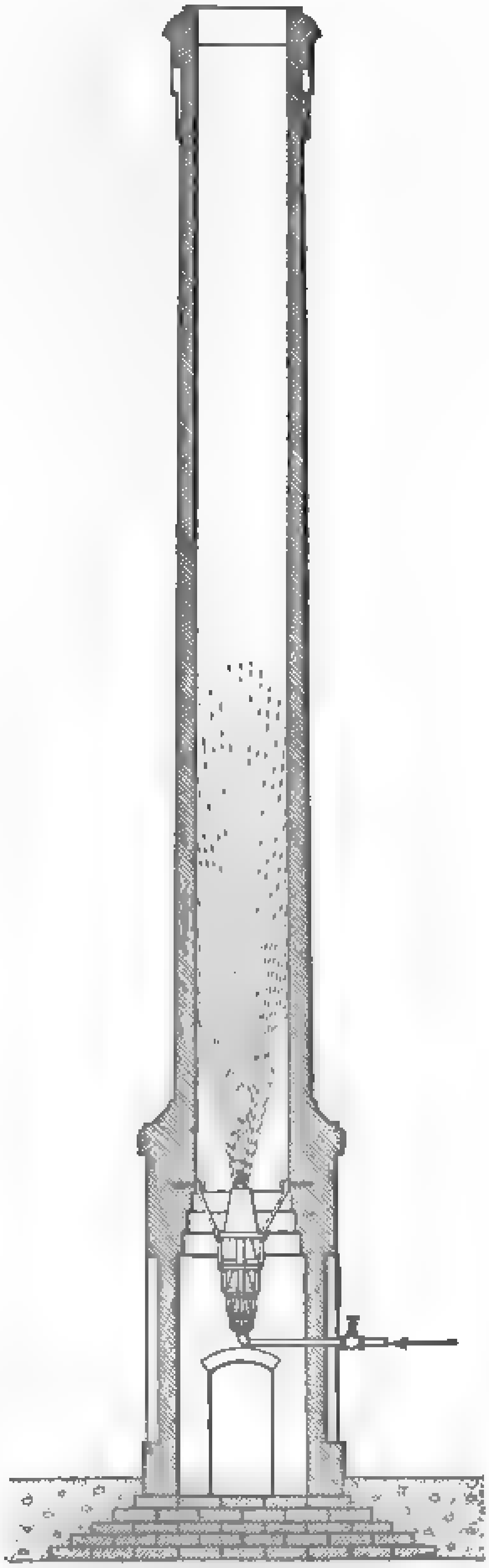

FIG. 10

## INDUCED DRAFT

**25. Induced or suction draft** may be described as an artificial means of inducing intensity of draft by the introduction of the appropriate appliances in the flue passages beyond the boilers.

**26. Steam Jet in Stack.**—The introduction of a steam jet at the base of the stack increases the intensity of the draft

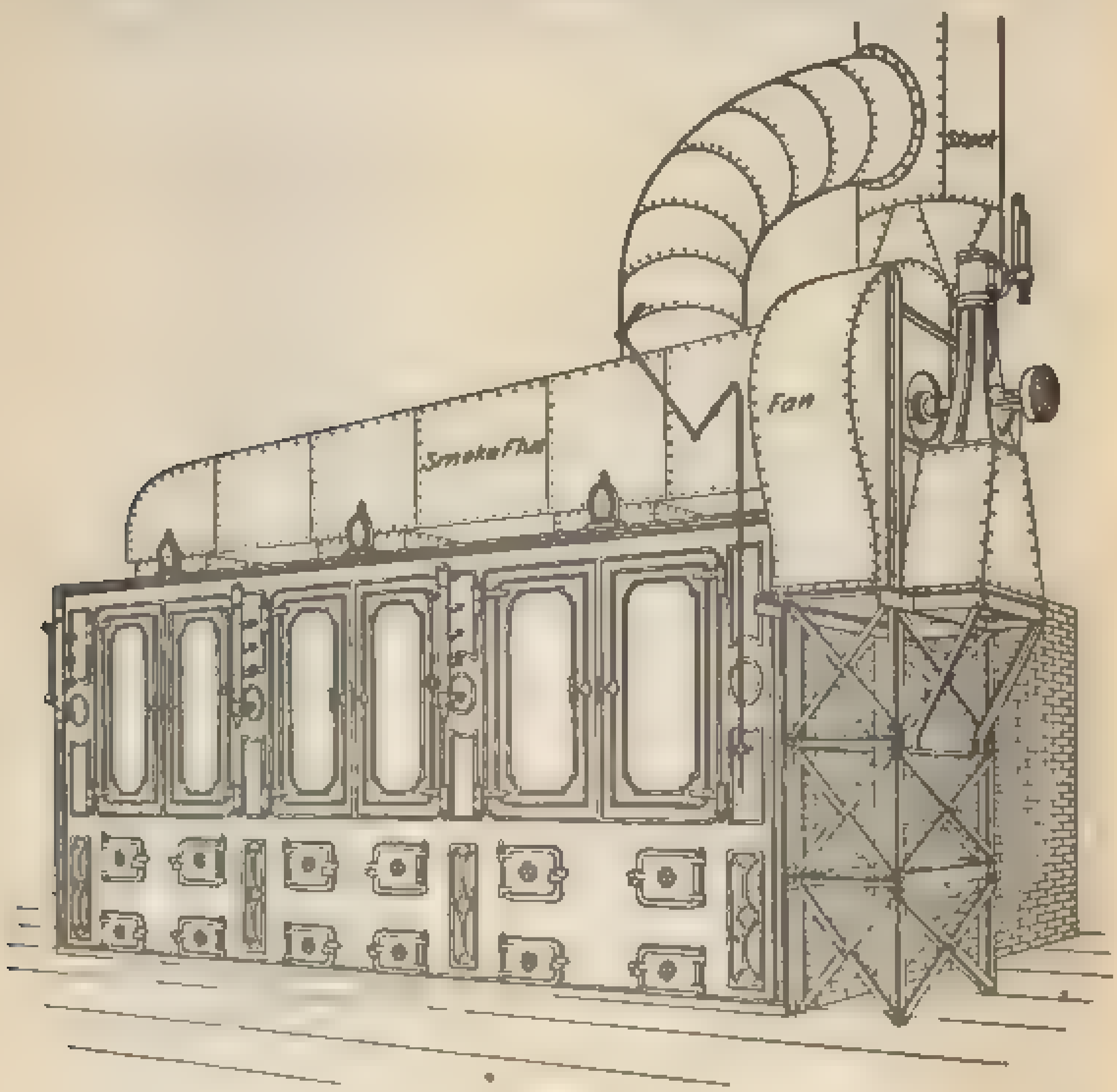


FIG. 11

by reason of the velocity of the steam issuing at high pressure. Fig. 10 illustrates a jet especially designed for this purpose. This method is not economical; it may serve to hasten a slow fire, but it is often found that the combined volume of steam added to the volume of gas from the furnaces is more than the chimney can quickly discharge.

**27. Fans.**—In this method slow-moving fans are arranged in the flues that carry off the hot gases. The suction created draws fresh air through the fire by reason of the reduced air pressure above the grates. The whole suction of the fans is through the fire, so that the intensity of the draft can be readily controlled by varying the speed of the fans. The fans may be driven by a direct-connected engine, an electric motor, or a belt from any convenient source of power. A simple application of this method, as installed by the American Blower Company, is illustrated in Fig. 11, and the arrangement may be modified to accommodate boiler equipments of any desired capacity. Greater reliability is obtained by installing two sets of fans, one of which may be used if the other is out of order.

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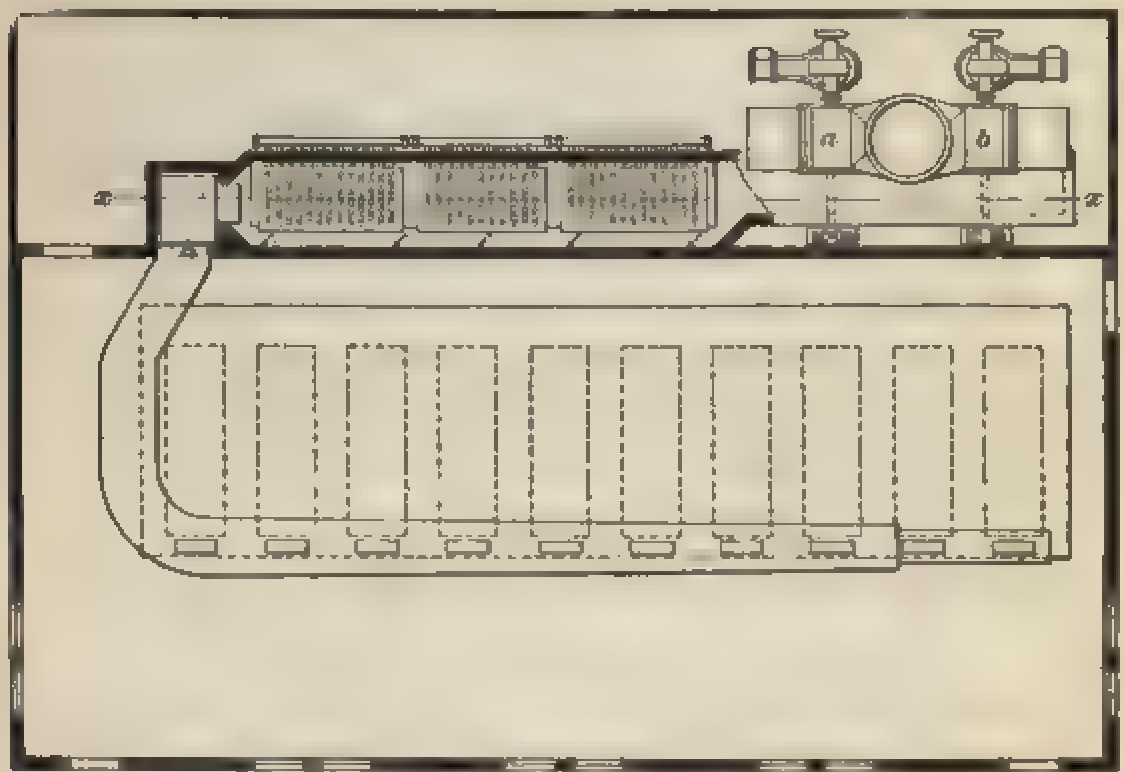
## ADVANTAGES AND DISADVANTAGES OF INDUCED DRAFT

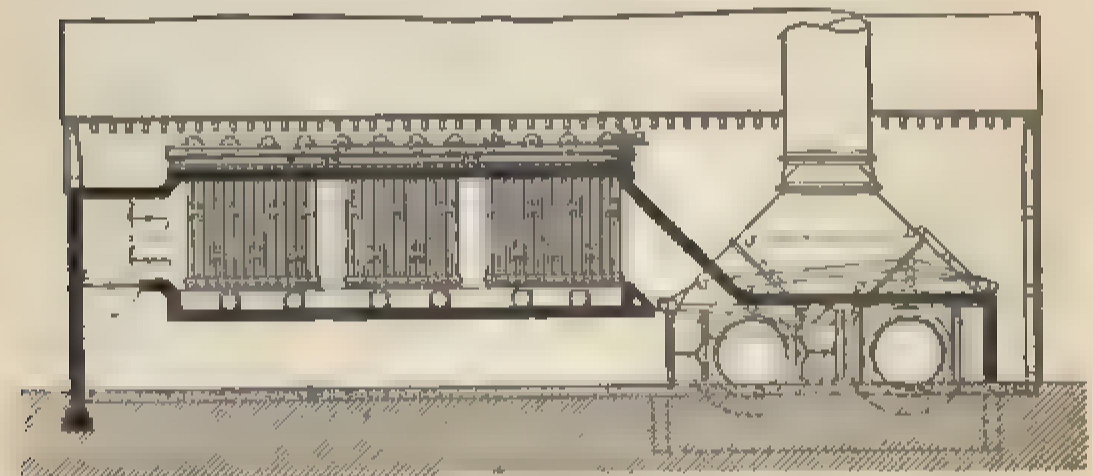
**28.** The principal advantages claimed for the induced-draft system are as follows: (*a*) The ability to closely regulate the amount of air required for perfect economy of combustion; (*b*) the providing of an efficient means for producing any desired intensity of draft at less first cost than the amount required to build a good chimney; (*c*) the ability to absolutely control a uniform draft regardless of atmospheric conditions, to burn low-grade coals, and to economically increase the intensity of the draft and thereby increase the evaporative capacity of the boilers.

These combinations of control render the method of induced draft well adapted for use in connection with economizers. Fig. 12 (*a*) and (*b*) shows plan and sectional views of an economizer installation used with induced draft. Two fans located at *a* and *b* and driven by independent engines, draw the products of combustion through the economizer and discharge them into the stack. Fig. 12 (*b*) is a sectional view along the line *x x* and shows the by-pass flue under the economizer and the various dampers and sliding doors by means of which the movement of the air is controlled.

It is claimed that the steam required to drive the fans for induced draft is from 1 to $1\frac{1}{2}$ per cent. of the steaming capacity of the boilers. The disadvantage of induced draft lies in this constant daily cost of operating and maintenance.



(a)



(b)

FIG. 12

The fan and enclosing iron casing are exposed to the action of the waste gases and are particularly liable to deterioration from this cause; the bearings must be cooled by water circulation, and are difficult to keep successfully lubricated. It is not considered wise to estimate less than 10 per cent.

per annum for depreciation and maintenance, on the induced-draft system, and to this must be added the cost of operation and interest on investment. It must not be understood that mechanical draft is under all circumstances equally economical or desirable. The economy of mechanical draft must depend on the conditions under which the plant is to be installed. The true measure of its value in each individual case must be estimated on a commercial basis with reference to the net saving in first cost of construction and in operating expenses, and a possible reduction in operating expense because of the ability to burn a low grade of coal. As before stated, the quantity of air required by mechanical methods may prove to be somewhat less than that needed with natural draft, but as air is obtained free of cost it is a question whether it pays to operate an engine and fan to cause its movement, or to induce such movement by natural means.

The advantages of the chimney are that after the first cost of construction has been met it requires no daily attention, the cost of repairs is trifling, and the products of combustion are delivered at such an elevation as not to cause a nuisance in the vicinity.

## STEAM BOILERS

**29.** The **boiler** must be considered one of the most important parts of the steam plant because within it is generated the steam that supplies the energy and sustains the movements of the whole plant. On the selection of a proper type of boiler and on its successful operation largely depend the economy of the entire station. If the boilers are of poor material and workmanship, deficient in number or capacity, or not properly proportioned, the reliability of the station will be imperiled and abnormal amounts paid for fuel and repairs. Boiler horsepower should not be understood as the equivalent of engine horsepower, but as already explained, a boiler horsepower is equivalent to the work done in evaporating $34\frac{1}{2}$ pounds of water per hour, at the pressure and temperature of unconfined boiling water.

## TYPES OF BOILERS

**30.** For electric power station purposes boilers of two classes are worthy of consideration. One class comprises **water-tube boilers**, in which the water travels through the tubes and the heated products of combustion circulate around the tubes. Boilers of this type are often called *safety boilers*. The *Babcock and Wilcox*, *Heine*, *Stirling*, and *Climax* are representatives of this class. The other class comprises **fire-tube boilers**, in which the water is contained in the shell and surrounds the tubes, and the products of combustion pass through the tubes. The *horizontal tubular*, the *vertical tubular*, and *Sederholm boiler* are representatives of this class.

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### WATER-TUBE BOILERS

**31. Babcock and Wilcox Boilers.**—The Babcock and Wilcox boiler, shown in Fig. 13, is a type that is used very largely in electric power stations. It consists essentially of a main horizontal drum *a a* and a series of inclined tubes *b*, *b*. Only a single vertical row of tubes is shown in the figure, but it will be understood that each nest of tubes is composed of several vertical rows; there are usually seven or eight vertical rows to each horizontal drum. The front and rear ends of the tubes *b*, *b* are expanded into hollow *headers* *d*, *d*. The front and rear headers are connected to the main drum by the tubes or risers *c*, *c*. In front of each tube, a handhole is placed in the header for the purpose of cleaning, inspecting, and renewing the tubes.

The boiler is supported from the I beams *e*, *e* by means of straps passing around the drum. These I beams are supported by cast-iron columns, the brickwork setting not being depended on as a means of support. This make of boiler, in common with all others of the water-tube type, requires a brickwork setting to confine the furnace gases. The furnace is placed under the front end of the nest of tubes. The bridge wall *f* is built up to the bottom row of tubes and another firebrick wall *f* is built between the top row of tubes

and the drum. The walls and baffle plates *g* force the hot furnace gases to follow a zigzag path back and forth between the tubes. The gases finally pass through an opening at *h* in the rear wall and from there to the chimney flue. The feedwater is introduced at the front of the boiler through the pipe *k* and the main steam pipe is attached at *l*. At the bottom of the rear row of headers is placed the mud-drum *m*; since this drum is at the lowest point of the water space, most of the sediment naturally collects there and can be blown off from time to time through the blow-off pipe *n* or

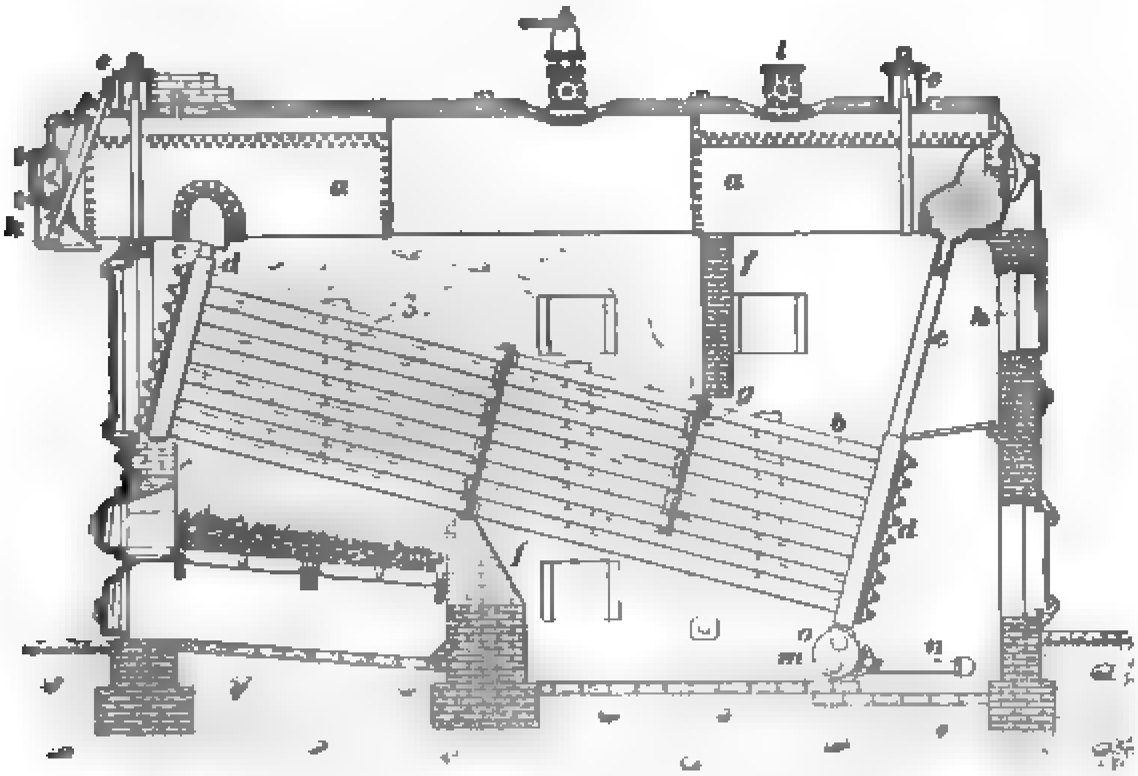

FIG. 13

removed through the handhole *o*. A manhole is provided in each end of drum *a* for access to the interior.

The water fed into the boiler through pipe *k*, passes to the back of the drum and descends through the back risers *c*. The water becomes heated in the tubes and rises through the front risers into the drum. There is thus a continuous circulation of water from front to back through drum *a a* and from back to front through tubes *b*, *b*.

**32. Heine Boiler.**—The Heine boiler, shown in Fig. 14, is another prominent example of the water-tube type. It

consists of a large main drum $A$ that is above and parallel with the nest of tubes $T$, $T$. Both drums and tubes are inclined at an angle with the horizontal that brings the water level to about one-third the height of the drum in front and about two-thirds in the rear. The ends of the tubes are expanded into the large wrought-iron water legs $B$, $B$. These water legs form the natural support of the boiler, the front legs resting on a pair of cast-iron columns $E$ that form part of the boiler front, while the rear leg rests on rollers at $F$.

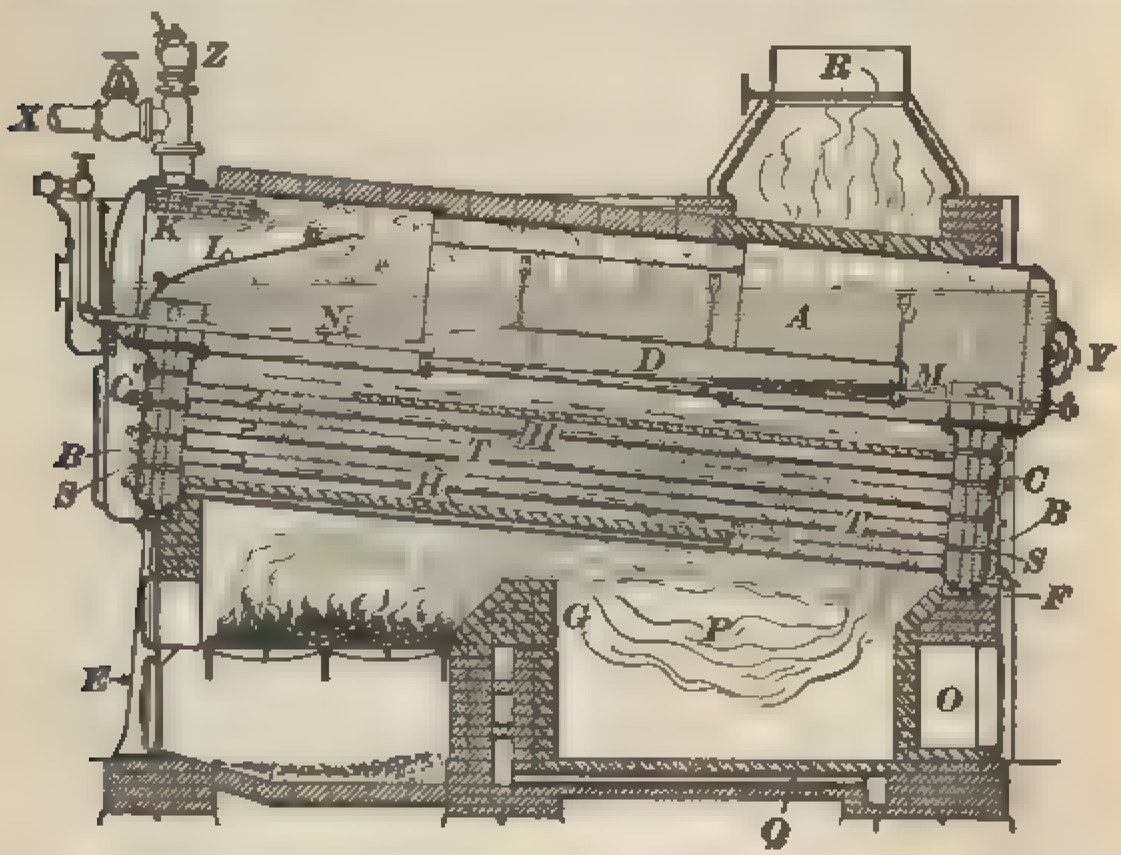


FIG. 14

These rollers allow the boiler to expand freely when heated. The bridge wall $G$ is made largely of firebrick and has openings in the rear to allow air to pass into the chamber $P$ and mix with the furnace gases. In the rear wall is an arched opening $O$ that is closed by a door and further protected by a thin wall of firebrick. When it is necessary to enter the chamber $P$, the wall may be removed and afterwards replaced.

The feedwater is brought in through the feedpipe $N$ that passes through the front head. As the water enters it flows into the mud-drum $D$, which is suspended in the main drum

below the water-line, and is thus completely submerged in the hottest part of the water. This high temperature is useful in precipitating the impurities contained in the feed-water and they may then be blown through the blow-off pipe *M*. Layers of firebrick *H*, *H* are laid at intervals along the rows of tubes and act as baffle plates, forcing the hot gases to pass

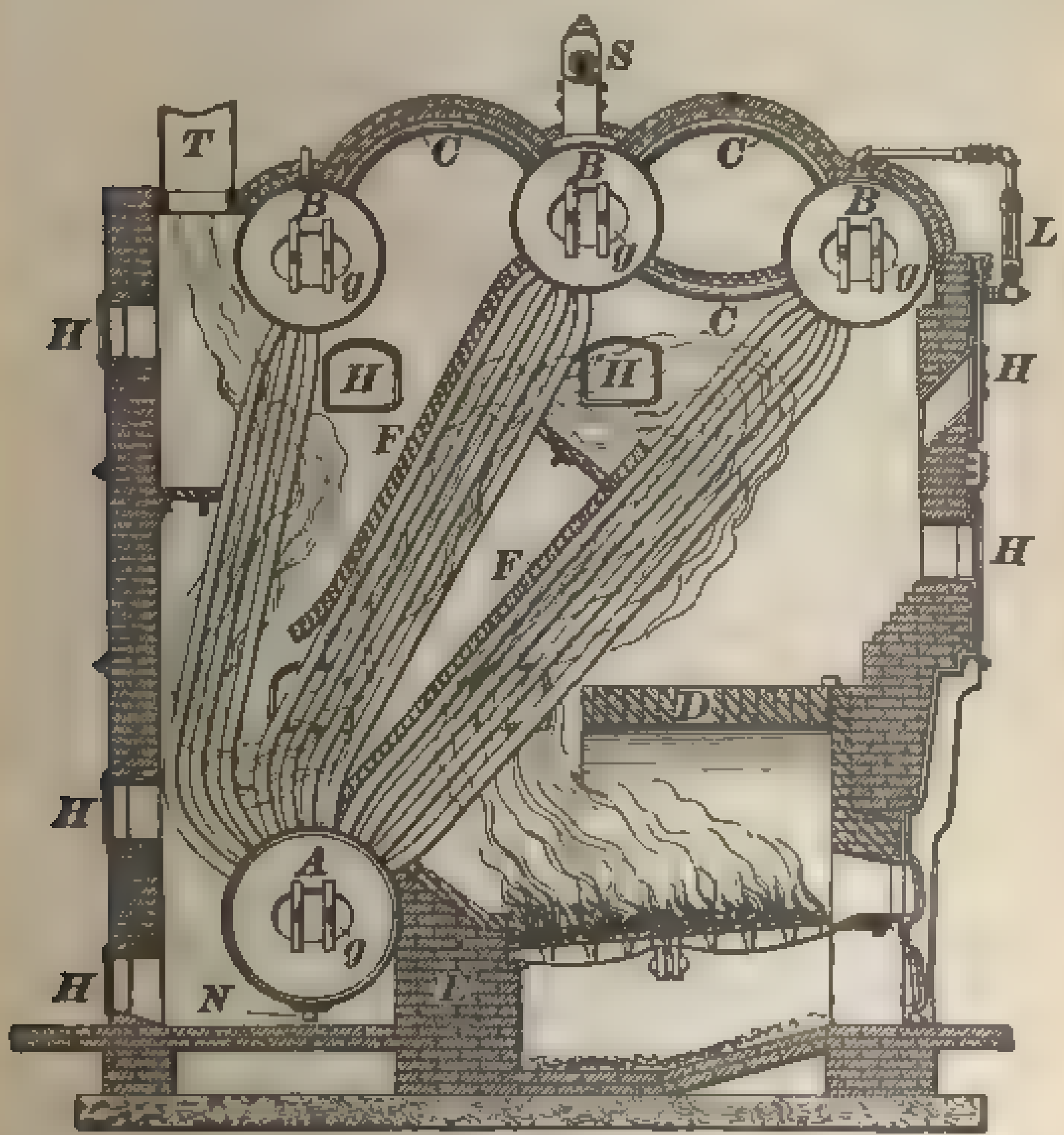


FIG 15

back and forth along the tubes until they escape through the chimney *R*. The steam is collected and freed from water by the perforated dry pipe *K*. The main steam pipe, with its stop-valve, is shown at *X*, the safety valve at *Z*. The deflecting plate *L* is placed in the front end of the drum to prevent a spray of mixed water and steam from the front header from entering the dry pipe *K*.

**33. Stirling Boiler.**—The Stirling water-tube boiler, shown in Fig. 15, is a departure from the regular type of water-tube boilers. It consists of a lower drum *A* connected with three upper drums *B*, *B*, *B* by three sets of nearly vertical tubes. These upper drums are connected by the curved tubes *C*, *C*, *C*. The curved forms of the tubes allow the different parts of the boiler to expand and contract freely without strain. The brickwork setting is provided with various openings *H*, *H* so that the interior may be inspected or repaired. The bridge *E* is lined with firebrick and is built in contact with the lower drum *A* and the front nest of vertical tubes. The arch *D* built over the furnace, in connection with the bafflers *F*, *F*, directs the course of the heated gases.

The cold feedwater enters the rear upper drum and descends through the rear nest of tubes to the drum *A*, which acts as a mud-drum and collects the sediment brought in by the water; a blow-off pipe *N* permits the removal of the sediment. The steam collects in the upper drums, and the steam pipe and safety valve are attached to the middle drum. The chimney *T* is located behind the rear upper drum and the water column *L*, with its fittings, is placed in communication with the first upper drum. All drums are provided with manholes *g*.

**34. Morrin Climax Boiler.**—Fig. 16 shows a vertical boiler of the water-tube type known as the **Climax boiler.** It consists of a stand pipe, or main vertical drum, *a* fitted with a large number of looplike tubes *b*, *b*, the ends of which are expanded into the shell. The furnace is circular, and in order to give free access to the fire, four furnace doors are provided. A deflector plate *d* is fitted to the shell a little above the water level, which tends to throw back any water carried up by the steam. The upper portion of the central shell is divided by a series of diaphragms *c*, *c* into a number of superheating chambers, through which the steam is compelled to circulate successively by the connecting looplike tubes. The steam thus becomes thoroughly dried and

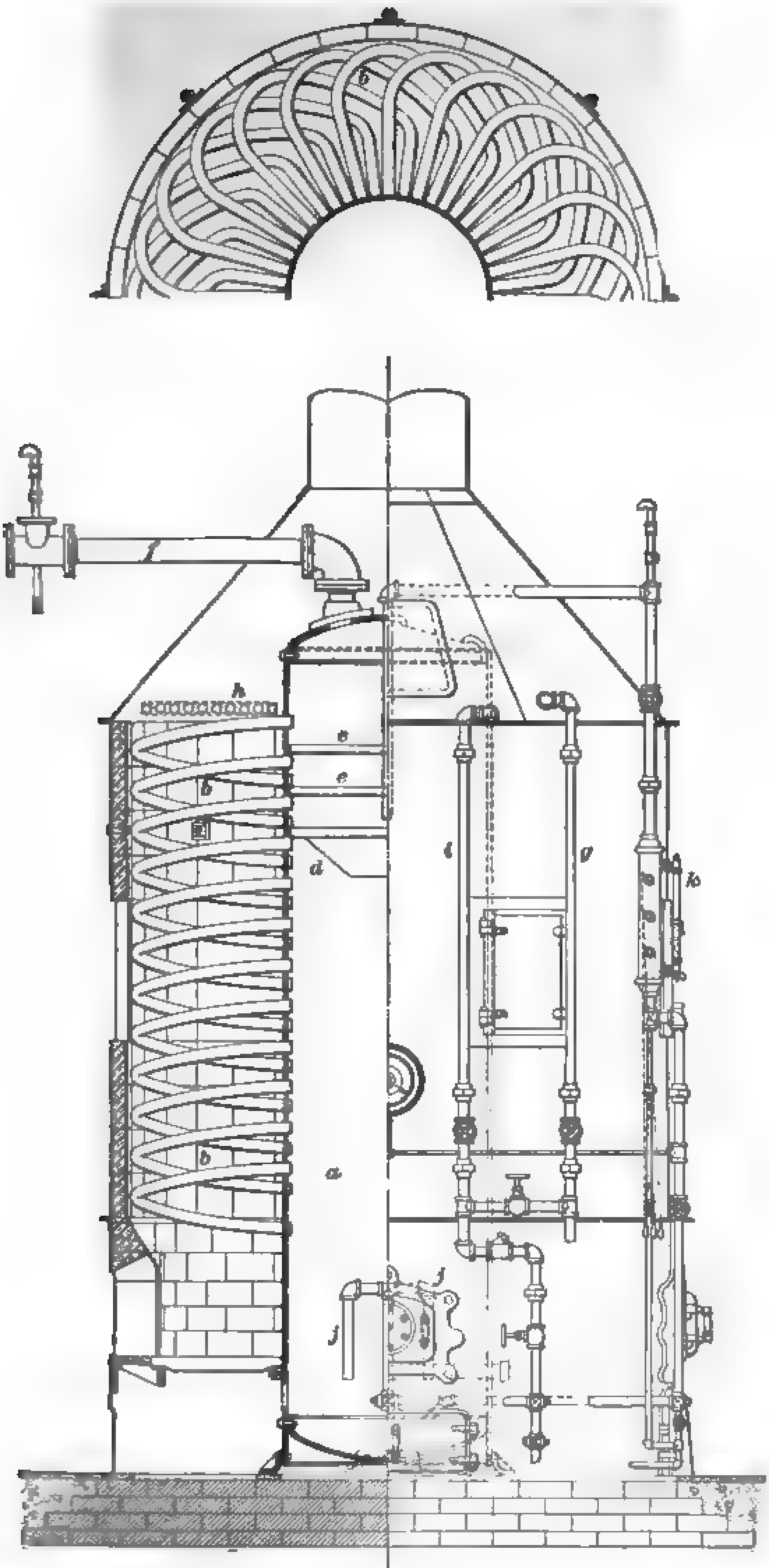


FIG. 16

somewhat superheated before it enters the main steam pipe *f*. The feedwater is discharged through the delivery pipe *g* into a spiral feed-coil *h* resting on top of the tubes, where it is heated to a high temperature. It leaves the coil through the pipe *i* and passes downwards, finally being discharged into the bottom through the internal feedpipes *j, j*. The water column *k* is connected to the top and bottom of the central shell. These examples give a general idea of the construction of water-tube boilers. There are so many types that it is impossible to describe them all. The advantages of the water-tube boilers are: economy of floor space, thin heating surface, joints not exposed to fire, large draft area, quick steaming, generally effective circulation, safety from explosions, ease of transportation, durability, and accessibility for cleaning. Water-tube boilers having restricted circulation are liable to accident in the event of pushing the steam production much beyond the rated capacity.

## FIRE-TUBE BOILERS

**35. Horizontal Return Tubular Boiler.**—This boiler is probably used more for general purposes in the United States than any other type. It is simple, effective, inexpensive, and easy to install. Fig. 17 shows a side view of it

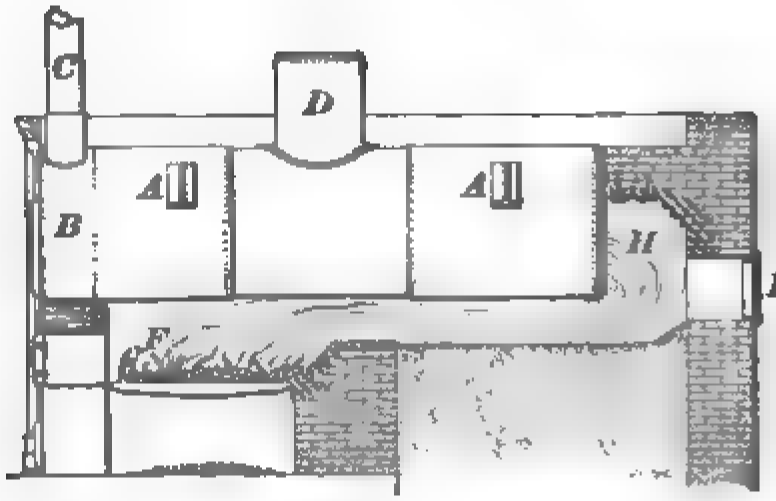


FIG. 17

and Fig. 18 a cross-section through the tubes. The boiler consists of a main outer cylindrical shell supported on the brickwork by the brackets *A, A* riveted to the shell. The tubes extend the whole length of the boiler and are expanded

into holes in the heads of the boiler. The front end of the shell projects beyond the head, forming the smokebox *B* into which opens the stack *C*. The steam pipe and safety valve are attached to the top of the steam drum *D* and a door *E* gives access to the rear of the boiler. The tubes form a series of flues through which the hot gases pass from the back of the boiler to the smokebox *B* and thence out of the stack. The gases pass to the back of the boiler under the shell and then return to the front through the tubes, hence the name given to the boiler. It is thus seen that the fire, or rather hot gases, pass through the tubes of the boiler and the tubes are surrounded by water contained in the outer shell, whereas in the water-tube boiler the reverse is the case.

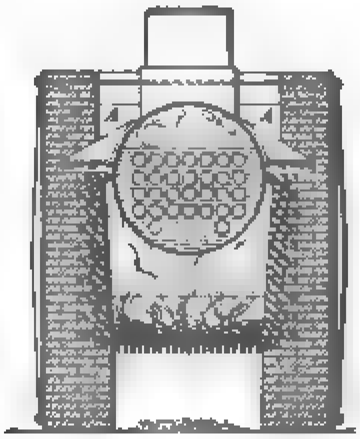

FIG. 18

**36. Vertical Tubular Boiler.**—Fig. 19 shows a vertical fire-tube boiler. The gases from the furnace *F* pass through the tubes *t*, *t* and out of the stack *K*. The steam is taken from the steam space *S* by means of the steam pipe *G*.

**37. Sederholm Boiler.**—This boiler is a special type of horizontal tubular boiler. It consists of a large main shell *a* fitted to tubes and connected to cylindrical drums *b* placed underneath, as shown in Figs. 20 and 21. These form a roof over the furnace and protect the main shell from the action of the flames, removing the danger of burning out the shell and rendering it possible to make the main shell as thick as required. It can therefore be made of large diameter, even when built for high pressure, and large units become possible. In Fig. 20 it is seen that each furnace drum *b* is connected to the main shell by means of three circulating pipes *c*, *d*, *c*, of which the central one extends almost to the bottom of the drum. The arrangement of these pipes insures a very effective circulation, and their curved shape gives considerable elasticity to the construction. This makes it possible to get up steam in a very short time, without giving rise to

any local strains, because the perfect circulation entirely prevents unequal heating. The main shell is fitted with tubes placed in two nests, leaving ample space in the center for a steady downward current of water. The boiler heads above the tubes are reenforced by doubling plates riveted on, and braced by strong stayrods *l*, *l*, Fig. 21, running the full length of the boiler. Access to the inside is obtained by means of one manhole on top for each furnace drum. The boiler is fitted with a perforated dry pipe *g* so arranged that the steam is taken from the highest part of the boiler.

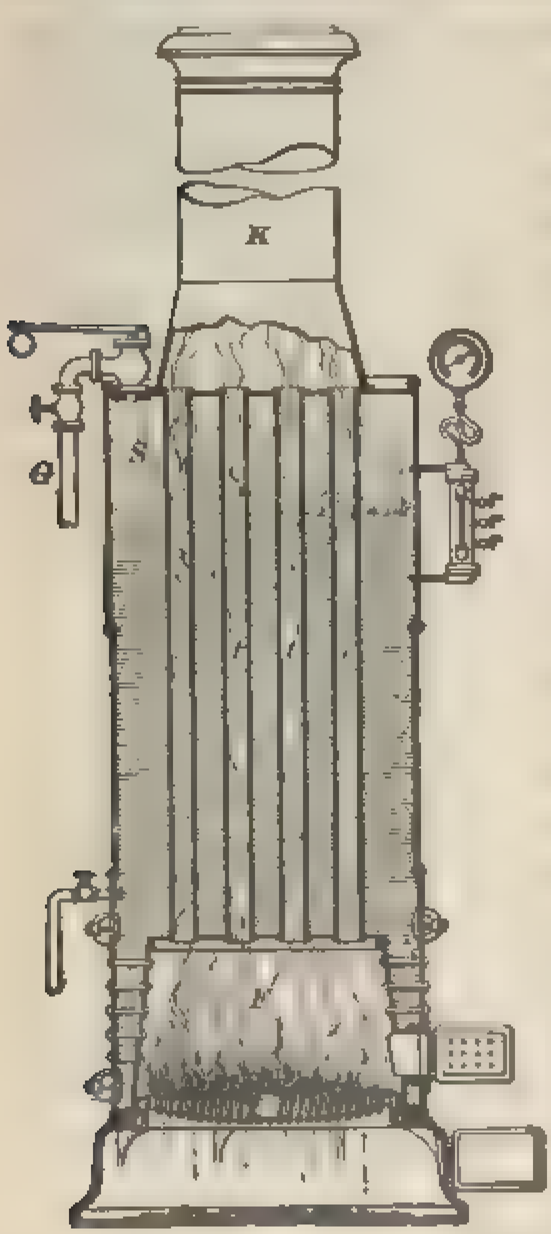

Fig. 19

A special feature is the unusually high furnace, which makes it possible to secure perfect combustion with the soft coals used in the Middle States; the special construction of the boiler setting still further favors this, and practically smokeless combustion is the result. Of course, any kind of special grate or furnace may be fitted to the boiler. The gases of combustion heat the lower side of the furnace drums, and then pass through the tubes *h*, Fig. 21, after which they are conducted either directly to the smokestack or around the main shell, according to circumstances. This secures a very uniform rate of evaporation throughout the whole boiler, resulting in the whole of the large liberating surface being effective, and therefore giving unusually dry steam, even when the boilers are forced to their limit. The exposed parts of the boiler are arranged to be covered with non-conducting material,

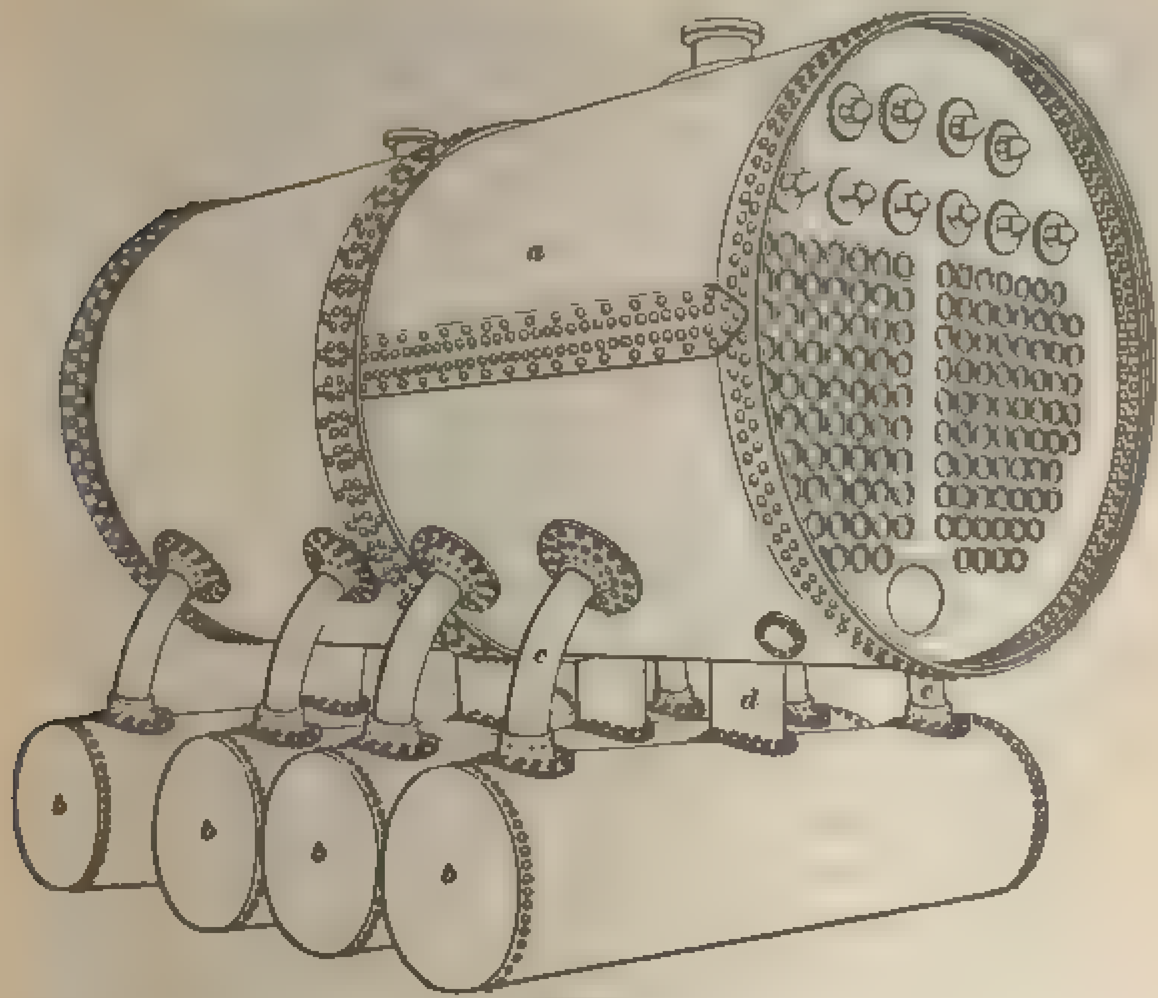

FIG. 20

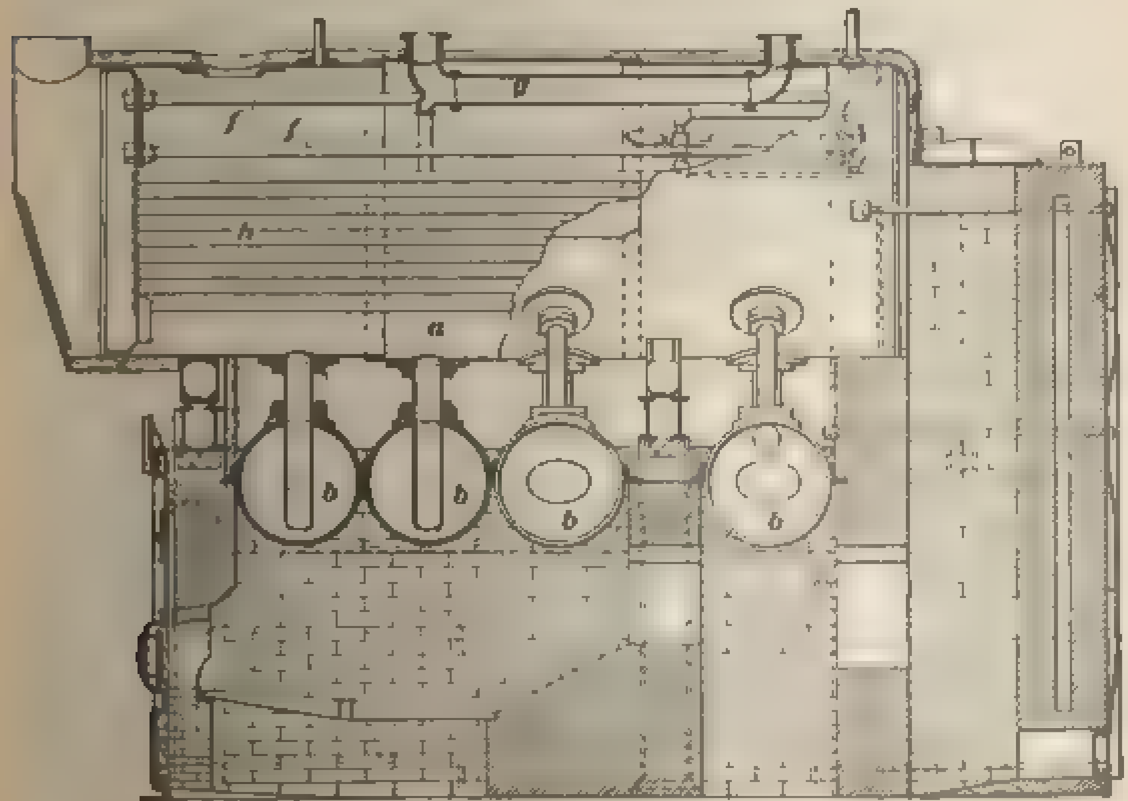

FIG. 21

and the boiler rests on an iron framework, so that no weight comes on the boiler setting. The brickwork is also very low, and the quantity of bricks required for the setting is therefore small. These boilers are built in sizes ranging from 150 to 600 horsepower and for pressures up to 250 pounds and higher.

## SELECTION OF BOILERS

**38.** When about to select boilers, the following details should receive careful consideration: (*a*) The area of the heating surface; (*b*) the area of the grate surface; (*c*) the area and route of the gas passages from the combustion chamber; (*d*) the free circulation of water in the boiler; (*e*) facilities offered for inspecting, cleaning, repairing, and keeping the boiler free from soot and ashes without, and free from scale and sediment within; (*f*) the kind of fuel to be used.

Experience has proved that boilers of the water-tube and the fire-tube type, when equally well designed and proportioned, give equally good economy, provided they are operated with the same skill and quality of fuel; therefore, no definite rule can be adopted as to which type should be selected. Where only moderately high pressures are required, and where there is ample floor space, the horizontal tubular boiler will give excellent results. Where pressures above 120 pounds are to be maintained, and more power is required per foot of floor space, the water-tube boilers will be most desirable.

The standard specifications of the Association of American Steam-Boiler Manufacturers may be accepted as embodying the best experience in the description of tubes, steel plates, riveting, etc. When inviting proposals for boilers, it is good practice to specify the number of square feet of heating surface required per rated horsepower. For water-tube boilers, this should not be less than ten, and for fire-tube boilers not less than twelve, and all competitive proposals should be figured out to the established basis, regardless of claims made by selling agents as to the advantages of their special design.

**39. Heating Surface.**—There has been a difference of opinion as to what constitutes the available heating surface of a boiler tube—the surface exposed to the flame, or that in contact with the water. A committee appointed by the American Society of Mechanical Engineers has decided in favor of the outside surface of the tube for both water-tube and fire-tube boilers. The Hartford Steam-Boiler Inspection and Insurance Company has for some time maintained the correctness of this as the true heating surface of a tube, and it is accepted by most boiler manufacturers.

The heating surfaces of value in water-tube boilers are the tubes and usually half the area of the steam drums; and for horizontal tubular boilers, half the area of the shell and all the surfaces of the tubes. The calculation of heating surface at the ends is an unnecessary refinement, as such surfaces are of but little real value.

**40. Influence of Type of Engines.**—When selecting boilers for an electric power station, the type of engine to be used must be taken into consideration, as the capacity of the engine to consume steam will create a relative demand on the boiler for the evaporation of more or less water into steam; therefore, the actual heating surface of the boilers selected should be considered in connection with the steam required by the type of engines to be used. The extent of heating surface in tubular boilers usually allowed per horsepower when the type of engine is known, is as follows:

| | Square Feet |
|---|---|
| Corliss compound condensing engine | 7½ to 8 |
| Simple Corliss condensing engine | 9 |
| Simple Corliss non-condensing engine | 10 to 11 |
| Automatic cut-off medium-speed engine | 11½ to 12 |
| High-speed automatic cut-off engine | 13 to 15 |

**41. Size of Boiler Units.**—For electric power station service, the units of boiler capacity should be selected in proportion to the unit of engine and generator capacity; this can be determined by allowing one, two, or three boilers per engine generator unit, according to the steam requirements

of the latter, and the steam-producing ability of the boilers. Water-tube boilers can be obtained in larger units of capacity than fire-tube boilers.

The load on the usual power station increases or diminishes at regular hours, excepting on the occasion of heavy storms or some unusual demand for current, and to successfully meet such emergencies boilers of quick-steaming and large reserve capacity are needed. Every electric power station should have sufficient extra boiler capacity to allow time for cleaning and repairs without interfering with the regular service demanded from the station. The boilers should be regularly inspected, their condition noted, and advantage taken of the season of small loads to put them in perfect condition for the next season of heavy loads.

**42. Evaporation.**—The maximum results that may be obtained for the evaporation from and at 212° F., from boiler tests, should not be taken as a basis for every-day working conditions of boilers in service. Tested under favorable conditions the best boilers will show from 8.5 to 11.5 pounds of water evaporated from and at 212° F., per pound of combustible, but in daily practice the average rate of evaporation will be from 6 to 9.5 pounds of water. This difference may be accounted for because of variable loads, careless firing, difference in quality of coal, condition of boilers, and other incidental causes that occur in daily service.

The coal required per horsepower-hour will be dependent on the economy of the combined equipment of boilers, engines, pumps, etc. of the station. Table V shows the average evaporation, in pounds per hour, from a feedwater temperature of 150° F. into steam of 100 pounds pressure, per each square foot of grate surface for different surface ratios and weight of fuel. The figures in this table are very conservative.

The *surface ratio* of a boiler is the ratio of the heating surface to the grate surface; or, in other words, the number of square feet of heating surface per square foot of grate surface. For example, from Table V it is seen that if a boiler has a

# TABLE V

## AVERAGE EVAPORATION, IN POUNDS PER HOUR, FROM A FEED TEMPERATURE OF 150° F. INTO STEAM AT 100 POUNDS PRESSURE, PER SQUARE FOOT OF GRATE SURFACE, AND FOR DIFFERENT SURFACE RATIOS AND WEIGHT OF FUEL

| Coal per Square Foot of Grate per Hour | Surface Ratio (Heating Surface + Grate Surface) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 30 | 32 | 34 | 36 | 38 | 40 | 42 | 44 | 46 | 48 | 50 | 52 | 54 | 56 | 58 | 60 |
| Pounds | Pounds of Water Evaporated per Hour | | | | | | | | | | | | | | | |
| 10 | 77 | 79 | 82 | 84 | 87 | 90 | 93 | 96 | 99 | 103 | 106 | 110 | 114 | 118 | 123 | 127 |
| 12 | 89 | 91 | 94 | 96 | 99 | 102 | 105 | 108 | 111 | 115 | 118 | 122 | 126 | 130 | 133 | 137 |
| 13 | 95 | 97 | 100 | 102 | 105 | 108 | 111 | 114 | 117 | 121 | 124 | 128 | 132 | 136 | 141 | 145 |
| 14 | 101 | 103 | 106 | 108 | 111 | 114 | 117 | 120 | 123 | 127 | 130 | 134 | 138 | 142 | 147 | 151 |
| 15 | 107 | 109 | 112 | 114 | 117 | 120 | 123 | 126 | 129 | 133 | 136 | 140 | 144 | 148 | 153 | 157 |
| 16 | 113 | 115 | 118 | 120 | 123 | 126 | 129 | 132 | 135 | 139 | 142 | 146 | 150 | 154 | 159 | 163 |
| 17 | 119 | 121 | 123 | 125 | 128 | 131 | 134 | 137 | 140 | 144 | 147 | 151 | 155 | 159 | 164 | 168 |
| 18 | 125 | 127 | 130 | 132 | 135 | 138 | 141 | 144 | 147 | 151 | 154 | 158 | 162 | 166 | 171 | 175 |
| 19 | 131 | 133 | 136 | 138 | 141 | 144 | 147 | 150 | 153 | 157 | 160 | 164 | 168 | 172 | 177 | 181 |
| 20 | 137 | 139 | 142 | 144 | 147 | 150 | 153 | 156 | 159 | 163 | 166 | 170 | 174 | 178 | 183 | 187 |
| 21 | 143 | 145 | 148 | 150 | 153 | 156 | 159 | 162 | 165 | 169 | 172 | 176 | 180 | 184 | 189 | 193 |
| 22 | 149 | 151 | 154 | 156 | 159 | 162 | 165 | 168 | 171 | 175 | 178 | 182 | 186 | 190 | 195 | 199 |
| 23 | 155 | 157 | 160 | 162 | 165 | 168 | 171 | 174 | 177 | 181 | 184 | 188 | 192 | 196 | 201 | 205 |
| 24 | 161 | 163 | 166 | 168 | 171 | 174 | 177 | 180 | 183 | 187 | 190 | 194 | 198 | 202 | 207 | 211 |
| 25 | 167 | 169 | 172 | 174 | 177 | 180 | 183 | 186 | 189 | 193 | 196 | 200 | 204 | 208 | 213 | 217 |
| 26 | 173 | 175 | 178 | 180 | 183 | 186 | 189 | 192 | 195 | 199 | 202 | 206 | 210 | 214 | 219 | 223 |
| 27 | 179 | 181 | 184 | 186 | 189 | 193 | 195 | 198 | 201 | 205 | 208 | 212 | 216 | 220 | 225 | 229 |
| 28 | 185 | 187 | 190 | 192 | 195 | 198 | 201 | 204 | 209 | 211 | 214 | 218 | 222 | 226 | 231 | 235 |
| 29 | 191 | 193 | 196 | 198 | 201 | 204 | 207 | 210 | 213 | 215 | 218 | 222 | 226 | 230 | 235 | 239 |
| 30 | 197 | 199 | 202 | 204 | 207 | 210 | 213 | 216 | 219 | 223 | 226 | 230 | 234 | 238 | 243 | 247 |

surface ratio of 40, and if 15 pounds of coal is burned per square foot of grate per hour, the boiler should, for each square foot of grate surface, be able to convert 120 pounds of water, supplied at 150° F., into steam at 100 pounds pressure per hour. The numbers at the tops of the vertical columns in Table V are surface ratios and the numbers in the body of the table are pounds of water evaporated per hour.

**43. Grate Surface.**—The allowance of grate surface, as compared with heating surface, varies with the type of boiler and the general custom of the builders, and should be carefully investigated. It varies from $\frac{1}{4}$ square foot to $\frac{1}{3}$ or $\frac{1}{2}$ square foot of grate surface to each 15 feet of heating surface; this is equivalent to from 60 to 30 square feet of heating surface per square foot of grate surface. The object of the grates is to furnish a surface to support the fuel in process of combustion, and offer the least obstruction to the passage of the air.

The proper proportion of grate surface of the boiler to the heating surface is important, to the end that the fuel may be burned most advantageously. Table V shows the ratio of heating surface to grate surface, but does not take any account of any special type of boiler, as with any well-designed and proportioned water-tube or tubular boiler the results will be practically the same.

**44. Grate Bars.**—The kind of fuel to be used should be determined, if practicable, because it will to some extent influence the style of grate bars to be employed. The rate of combustion, intensity of draft, and quality of fuel will determine the extent of grate surface. The smaller sizes of coal, because of packing together more closely, offer more resistance to the passage of the air through the fresh fuel than the coarse coal, and the coal burns more slowly; also a greater intensity of draft is necessary to maintain the circulation of air through the fire. When a coarse coal is used the air spaces are wider, the air goes through the fire more readily, and great care is required to prevent holes

being burned out in the bed of the fire, resulting in loss of economy.

The sizes of air space required for grate bars for different kinds of fuel are indicated in Table VI.

TABLE VI

SIZE OF GRATE BARS AND AIR SPACE FOR DIFFERENT KINDS OF FUEL

| Kind of Fuel | Size of Bar Inch | Width of Air Space Inch | Kind of Fuel | Size of Bar Inch | Width of Air Space Inch |
|---|---|---|---|---|---|
| Anthracite, lump. . . . | $\frac{1}{2}$ | $\frac{3}{4}$ | Bituminous, run of mine | $\frac{3}{8}$ | $\frac{1}{2}$ |
| Anthracite, egg . . . . | $\frac{1}{2}$ | $\frac{3}{4}$ | Bituminous, slack . . . | $\frac{5}{16}$ | $\frac{3}{8}$ |
| Anthracite, nut. . . . . | $\frac{3}{8}$ | $\frac{1}{2}$ | Bituminous, lump . . . | $\frac{1}{2}$ | $\frac{5}{8}$ |
| Anthracite, pea. . . . . | $\frac{3}{8}$ | $\frac{3}{8}$ | Wood . . . . | $\frac{3}{8}$ | $\frac{3}{4}$ |
| Anthracite, buckwheat | $\frac{3}{8}$ | $\frac{5}{16}$ | Sawdust. . . | $\frac{5}{16}$ | $\frac{1}{4}$ |

**45. Coal Burned per Square Foot of Grate Surface.**—With anthracite of quick combustion, high furnace temperature, and little flame, a limit is reached to the value of extra tube surface. From 5 to 28 pounds of anthracite can be burned successfully per hour per square foot of grate surface with natural draft, and the heating surface may reach as high as 45 square feet per square foot of grate surface. With bituminous coal, which is gaseous and requires more combustion space, larger tube surface becomes more valuable, and may be from 45 to 55 square feet per square foot of grate surface. Ordinarily, from 8 to 15 pounds of bituminous coal may be burned per hour per square foot of grate surface. The heating surface and combustion space should be so proportioned that the escaping gases

## TABLE VII

COAL CONSUMPTION PER SQUARE FOOT OF GRATE SURFACE FOR DIFFERENT AREAS OF GRATES AND VALUES OF TOTAL FUEL CONSUMED PER HOUR

| Square Feet of Grate Surface | Pounds of Fuel Burned per Hour | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 50 | 100 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1,000 |
| 4 | 12.50 | 25.00 | 50.00 | 75.00 | 100.00 | 125.00 | 150.00 | 175.00 | 200.00 | 225.00 | 250.00 |
| 6 | 8.33 | 16.60 | 32.30 | 50.00 | 66.60 | 83.30 | 100.00 | 116.00 | 133.30 | 150.00 | 166.60 |
| 8 | 6.25 | 12.50 | 25.00 | 37.50 | 50.00 | 62.50 | 75.00 | 87.50 | 100.00 | 112.50 | 125.00 |
| 10 | 5.00 | 10.00 | 20.60 | 30.00 | 40.00 | 50.00 | 60.00 | 70.00 | 80.00 | 90.00 | 100.00 |
| 12 | 4.16 | 8.33 | 16.60 | 25.00 | 33.30 | 41.66 | 50.00 | 58.33 | 66.60 | 75.00 | 83.32 |
| 14 | 3.57 | 7.14 | 14.28 | 21.40 | 28.57 | 35.71 | 42.80 | 50.00 | 57.14 | 60.90 | 71.42 |
| 16 | 3.12 | 6.25 | 12.50 | 18.70 | 25.10 | 31.25 | 37.40 | 43.75 | 50.20 | 56.25 | 62.50 |
| 18 | 2.77 | 5.55 | 11.11 | 16.60 | 22.22 | 27.70 | 33.20 | 38.80 | 44.44 | 50.00 | 55.40 |
| 20 | 2.50 | 5.00 | 10.00 | 15.00 | 20.00 | 25.00 | 30.00 | 35.00 | 40.00 | 45.00 | 50.00 |
| 22 | 2.27 | 4.55 | 9.11 | 13.68 | 18.22 | 22.72 | 27.36 | 31.81 | 36.44 | 40.90 | 45.44 |
| 24 | 2.08 | 4.16 | 8.33 | 12.50 | 16.66 | 20.83 | 25.00 | 28.33 | 33.32 | 37.50 | 41.66 |
| 26 | 1.92 | 3.84 | 7.69 | 11.53 | 15.38 | 19.23 | 23.06 | 26.92 | 30.76 | 34.61 | 38.46 |
| 28 | 1.78 | 3.57 | 7.14 | 10.71 | 14.28 | 17.85 | 21.42 | 25.00 | 28.56 | 32.14 | 35.60 |
| 30 | 1.66 | 3.33 | 6.66 | 10.00 | 13.33 | 16.66 | 20.00 | 23.33 | 26.66 | 30.00 | 33.32 |
| 32 | 1.56 | 3.12 | 6.25 | 9.37 | 12.50 | 15.62 | 18.74 | 21.87 | 25.00 | 28.12 | 31.25 |
| 34 | 1.47 | 2.94 | 5.88 | 8.82 | 11.77 | 14.70 | 17.64 | 20.58 | 23.54 | 26.47 | 29.40 |
| 36 | 1.38 | 2.77 | 5.55 | 8.33 | 11.11 | 13.88 | 16.66 | 19.44 | 22.22 | 25.00 | 27.76 |
| 38 | 1.31 | 2.63 | 5.25 | 7.89 | 10.50 | 13.15 | 15.78 | 18.42 | 21.00 | 23.68 | 26.30 |
| 40 | 1.25 | 2.50 | 5.00 | 7.50 | 10.00 | 12.50 | 15.00 | 17.50 | 20.00 | 22.50 | 25.00 |
| 42 | 1.19 | 2.38 | 4.73 | 7.14 | 9.52 | 11.90 | 14.28 | 16.66 | 19.04 | 21.42 | 23.80 |
| 44 | 1.13 | 2.27 | 4.54 | 6.81 | 9.09 | 11.36 | 13.62 | 15.99 | 18.18 | 20.45 | 22.72 |
| 46 | 1.08 | 2.17 | 4.34 | 6.52 | 8.69 | 10.86 | 13.04 | 15.21 | 17.38 | 19.56 | 21.72 |
| 48 | 1.04 | 2.08 | 4.16 | 6.29 | 8.33 | 10.41 | 12.58 | 14.66 | 16.66 | 18.75 | 20.82 |
| 50 | 1.00 | 2.00 | 4.00 | 6.00 | 8.00 | 10.00 | 12.00 | 14.00 | 16.00 | 18.00 | 20.00 |

from anthracite do not exceed 380° to 400° F., and from bituminous coal 415° to 460° F.

**46. Desirability of Ample Flue Areas.**—The flue openings and other passages from the furnace must be of sufficient area to permit the volume of the products of combustion a free and unobstructed exit after leaving the boiler. The volume of the products of combustion will, of course, depend largely on the weight of fuel burned, and the area of the openings for the escape of the hot gases has considerable to do with the successful operation of the boiler. Special emphasis is placed on the importance of an intense draft. An electric power station with a slow draft may fail to get up steam sufficiently quick to meet the demands of a sudden load. When the draft is slow and the coal is of a poor quality, and burns slowly, a larger grate area will be necessary to give the same results that would be obtained with a better coal, stronger draft, and higher rates of combustion. Table VII shows the coal consumption per square foot of grate surface per hour for different areas of grates and values of the total pounds of fuel consumed per hour. The first column at the left-hand side indicates the area of grate surface, the columns parallel thereto indicate the pounds of coal burned per hour per square foot of grate surface, and the row of figures at the top of columns indicates the total pounds of coal from 50 pounds to 1,000 pounds per hour burned at the several ratios. The heavy zigzag line shows about the maximum limit for economical consumption of fuel under favorable conditions. For example, in order to burn 400 pounds of fuel per hour with 12 square feet of grate area, the consumption per square foot of grate surface would be $\frac{400}{12} = 33.3$, as indicated in the column headed 400 and opposite the grate area 12. This consumption is at the extreme limit for economical combustion, as the number 33.3 is just under the zigzag line.

## LOCATION OF BOILERS

**47.** The convenient and proper placing of boilers is an important matter. Special care should be taken to see that sufficient space is allowed to withdraw and renew tubes, and also that the boilers are accessible for examination, cleaning, and repairs. Fig. 22 shows an improper location for a boiler setting because the external wall is exposed to the weather and also carries the wall of the building; Fig. 23 shows a proper location for the same boiler setting. In a plant of comparatively small capacity, the boilers should be so placed that there is convenient access between the fireroom and the engine room, as there will be certain times during hours of light load when one man can look after both; in larger plants, it may not be possible to carry out this arrangement. If water-tube boilers are used they should be set in batteries of two, and each group of boilers should be easily accessible on all sides. Where horizontal tubular boilers are used several may be set side by side in the same battery.

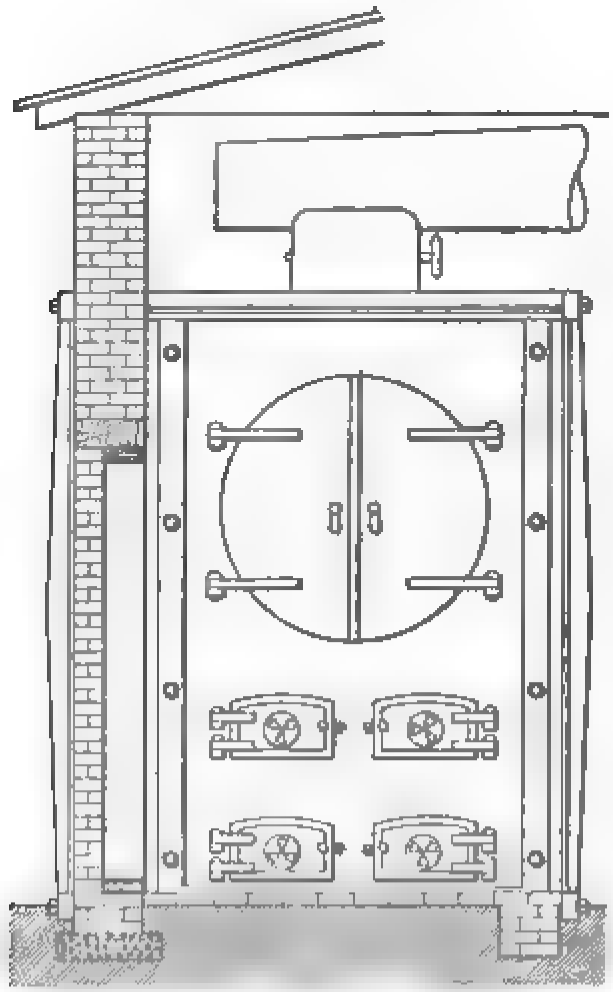

FIG. 22

**48. Boiler Foundations.**—The foundation walls should be built to the level of the floor line and if possible should be started on rock or solid earth. The excavation should not be less than 3 feet deep; the foundation walls should be laid of good concrete or broad flat stones in cement mortar. If soft earth should be encountered, the entire area should be

excavated; if the earth is constantly wet, lay two courses of 3" × 12" plank and fill with concrete to within 1 foot of the floor line, from which level the foundation walls may be started. Where boilers are set above a basement or on upper floors, it is of course presumed that the columns, girders, and beams of the building have been substantially designed to support the load, which will consist of the weights of the brick-work, boilers, and water combined.

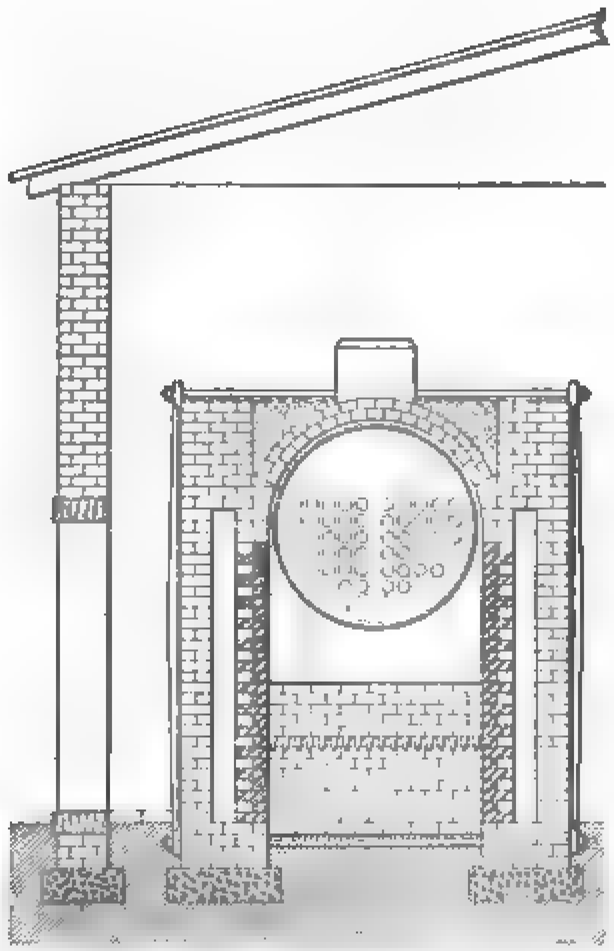

FIG. 23

**49. Boiler Settings.** The plans for boiler settings vary with the type and size of the boiler, but certain features of good practice apply to all cases. The proper design and execution of the work is a matter of great importance, as the boiler setting is subjected to greater strains in proportion to the weight supported, than is the case with ordinary walls because of the extremes of temperature within and without the enclosing walls. The best standard of work will include the following points:

(*a*) The rear and side walls should be double with an air space between, to avoid the leakage of cold air through the walls.

(*b*) The double walls need not be tied together, but at every fifth or sixth course the bricks can project from the outer wall and touch the inner; a 1-inch air space is quite sufficient. Fig. 23 illustrates this method but emphasizes the air space to make it clear.

(*c*) For a durable setting the outer wall should be one brick thick, or a 9-inch wall, and the inner wall should be one and one-half bricks thick, or a 13-inch wall.

(*d*) The furnace walls should be lined with the best firebrick having six courses laid with the length of the bricks or ends exposed to the fire, and the seventh course a row of stretchers. When laid in this way the furnace wall will stand twice as long without repairing; the ends of the bricks will burn off or fuse away, but the wall will not fall down as is frequently the case when five courses of stretchers are laid with the sixth course headers. The remaining part of the combustion chamber can be lined with the usual single course of firebrick stretchers tied into the inner wall.

(*e*) The joints of the red brickwork should not exceed $\frac{3}{16}$ inch, and for all red brick a good mortar can be made of two parts lime, one part hydraulic cement, and four parts clean, sharp sand. Each brick should be dipped in water before laying. The firebrick should be laid in a mortar made of firebrick ground to a fine powder, and mixed with water to a proper consistency. The joints should be very close, not exceeding $\frac{1}{8}$ inch.

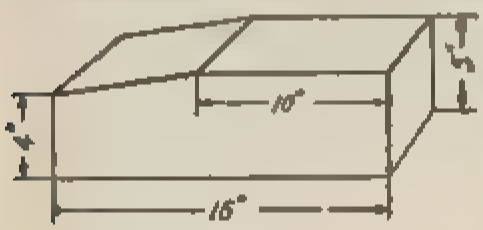


FIG. 24

(*f*) The bridge wall, if laid of the usual firebrick according to standard methods, will soon be knocked down. The form of firebrick blocks shown in Fig. 24 laid side by side with fireclay joints and backed up with the usual inclined flame bed will stand many years of service.

This setting will save in repairs many times its cost. Ample time, from 30 to 60 days, should be allowed for the brickwork to dry out, and a slow, easy fire should be used for several days before getting up steam pressure.

**50. Ash-Pits.** Where ashes are removed from a basement below the boiler room, a suspended hopper-shaped ash pocket built of $\frac{5}{16}$-inch boiler plates may be used; the hopper should be lined with slabs of firebrick, and the opening closed with a vizor gate and lever. Another plan is a

pocket built of brickwork with a front delivery to car or conveyer; this arrangement is shown at *a*, Fig. 25, which shows a cross-sectional view of the boiler plant for a large station. Where neither of these can be adopted, the sides of the ash-pit should be sloped at an angle of 45° from the walls and the floor should slope from the front and rear to the center. The floor of ash-pit should be of vitrified brick laid on edge in cement mortar, well grouted, and made water-tight. The floor of the boiler room in front of the boilers will be very durable if made of vitrified brick laid on edge and grouted; the bed should be 6 inches of concrete with 1 inch of sand to level the brick. All water and blow-off pipes that can be laid below the floor line, are preferably so located in channels of ample size. The walls of pipe channels are easily formed of concrete, and iron plates will make most satisfactory covers.

## AUTOMATIC STOKERS

**51.** **The automatic stoker** is a device for reducing the labor of hand firing, maintaining a uniform rate of fuel supply, and more uniform and perfect combustion and furnace temperatures. Automatic stokers may be divided into two classes: *overfeed* and *underfeed*.

### OVERFEED STOKERS

**52.** **Roney Mechanical Stoker.**—This stoker, which is shown in Figs. 26 and 27, is one of the most widely used stokers of the **overfeed type.** Fig. 26 is a perspective view of it, as applied to a horizontal tubular boiler, and Fig. 27 a sectional view, showing the relation of the different parts. Like parts have been lettered the same in the two figures. The coal is fed into the hopper *a*, from which it is pushed by the pusher plate *b* on to the dead plate *c*, where it is heated and coked. From *c*, the coke passes to the grate *d d d*, which consists of cast-iron bars that form a series of steps; each bar is supported at its ends by trunnions and is connected by an arm to a rocker bar *i*, Fig. 27, which is

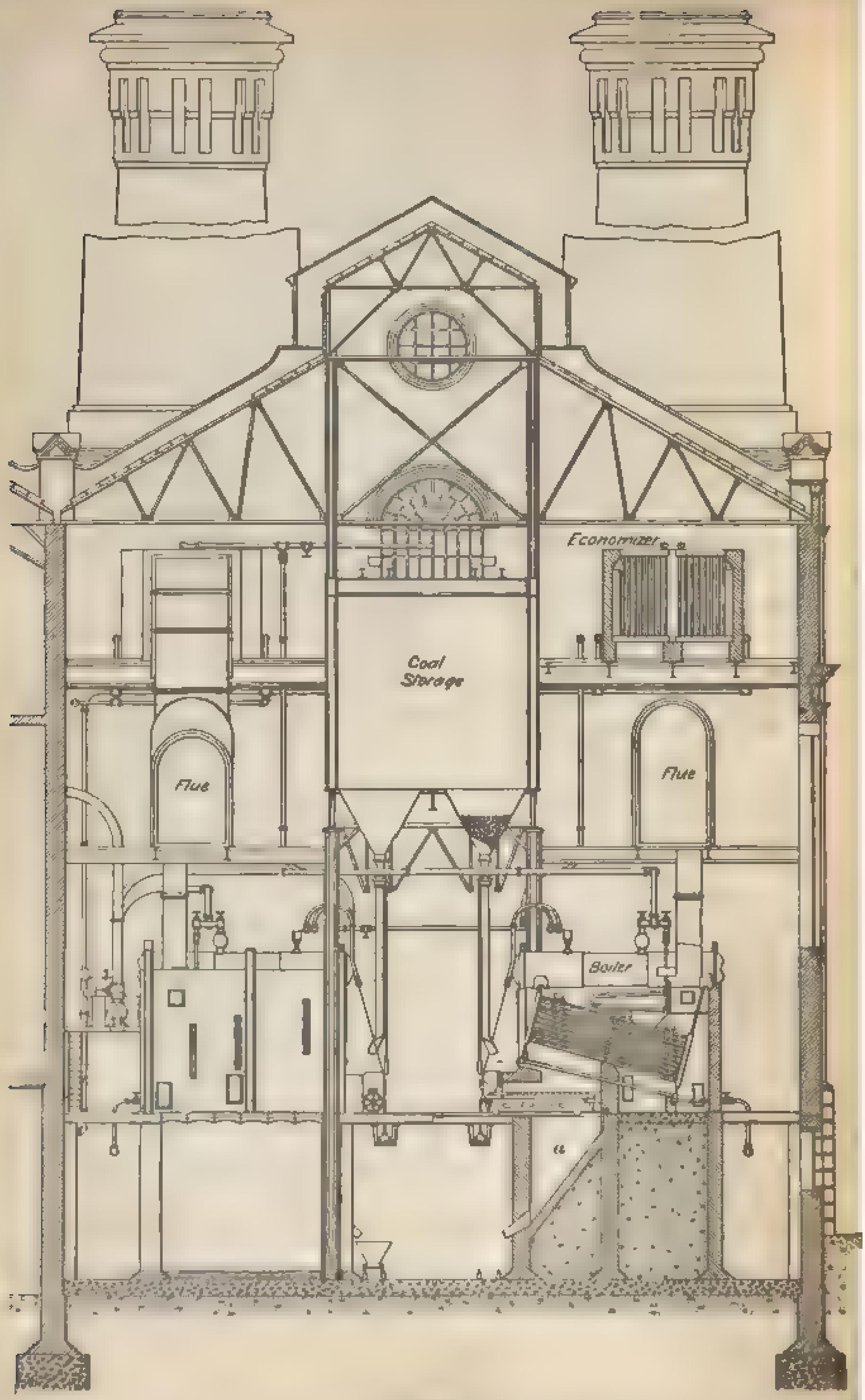


Fig 25

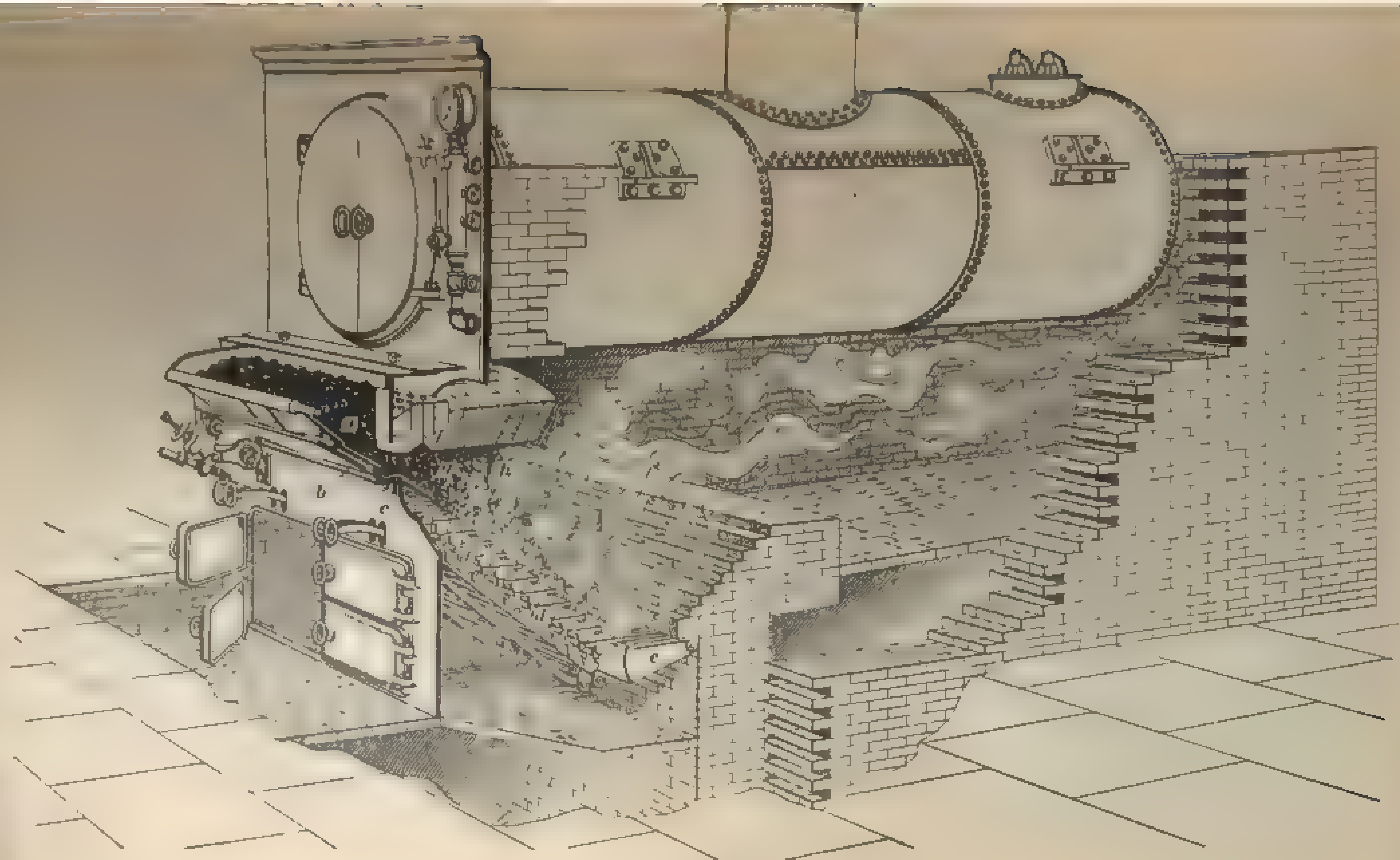


Fig. 26

slowly moved to and fro by an eccentric on the shaft *s*, so as to rock the grates back and forth between the stepped position shown and an inclination toward the back of the furnace; the grates thus gradually move the burning coke downwards. The ashes and clinkers are discharged from the lower grate bar on to the dumping grate *e*, which can be lowered so as to drop them into the ash-pit below. A guard *f*, Fig. 27, may be raised, as shown by the dotted lines, so as to prevent coke or coal from the grate bars from falling into the ash-pit when the dumping grate is lowered. Air for burning the gases is admitted in small jets through holes in the hot **air tile** *g*, and the mixture of gas and air is burned in the hot chamber between the firebrick arch *h* and the bed of burning coke below.

The **Roney stoker** is designed especially for burning all grades of bituminous coal, but may be successfully used for burning fine anthracite.

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### ENDLESS-CHAIN, OR TRAVELING, GRATES

**53.** Another class of stokers that belongs to the over-feed type is the **traveling grate**; in this stoker, the coal is carried into the furnace by means of a slowly moving grate made in the form of an endless chain. Among the many types of chain-grate stokers on the market are the Duluth stoker, the Green traveling-link grate, the McKenzie furnace, and the Playford chain-grate stoker. All traveling-grate stokers are similar in general character; the fuel is supplied from a hopper to the front end of a moving grate, it ignites and burns as the grate travels to the rear, and the refuse products of combustion are dumped at the rear end of the furnace near the bridge wall to an ash-pit below. These stokers are generally moved by a small engine or by an electric motor. The average power required to move the grate varies with the size and speed; it ranges from $\frac{1}{8}$ to $\frac{3}{4}$ horsepower. The traveling grates vary in details of construction, in the style of the bars, and methods of coupling the sections together. Extending across the front of the furnace is a

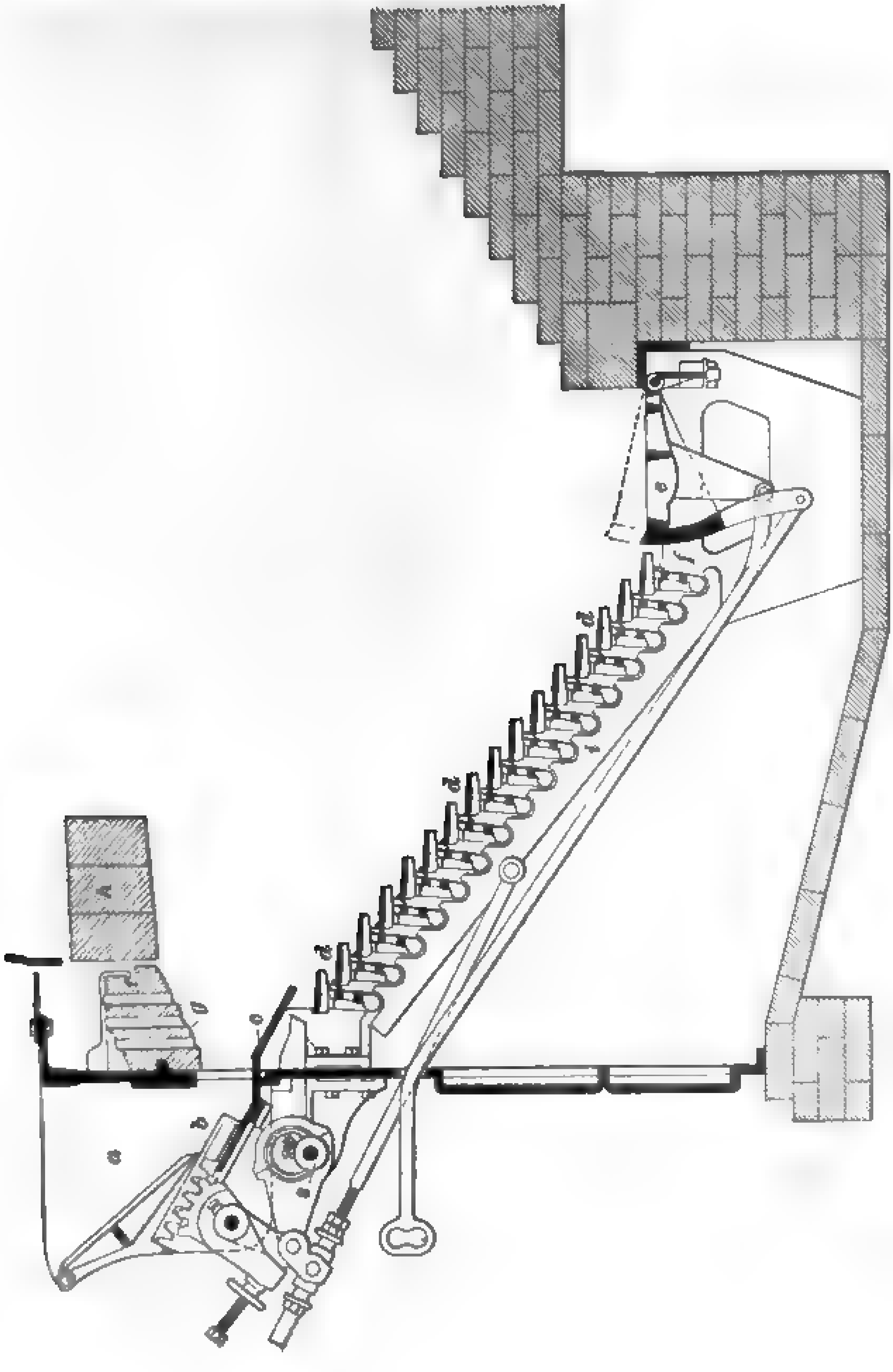

FIG. 27

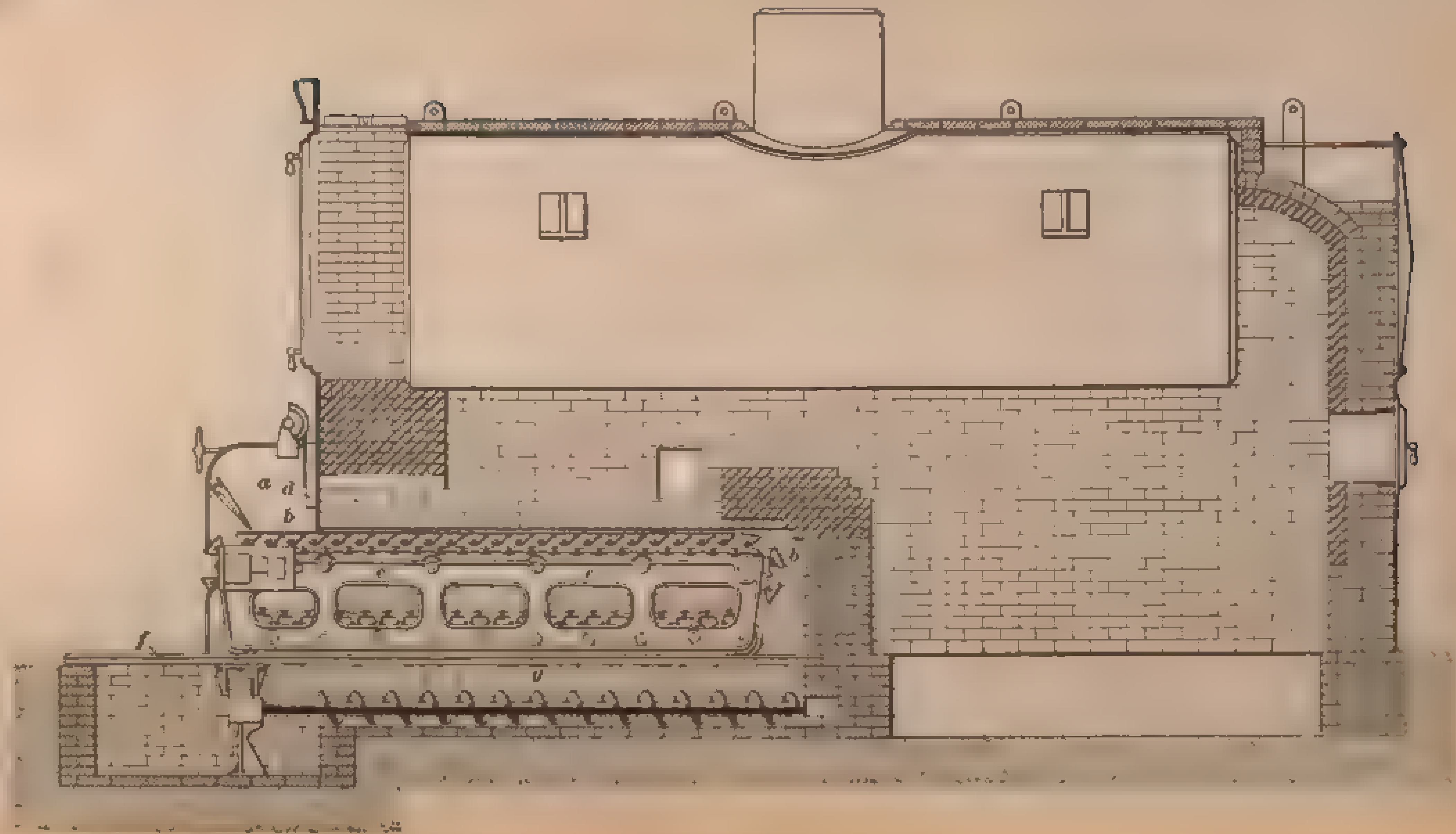

FIG 29

hopper into which coal may be shoveled or automatically distributed by tubes from overhead storage. The feed of coal is adjustable and may be graded to whatever thickness of fire may be desired, even to an overload on the boilers.

Traveling grates are set up on substantial frames, and mounted on wheels and a track so that they can be run out from under the furnace for inspection or repairs. It is usual to build a firebrick arch at the front end of the furnace, where the heat is most intense; this facilitates the coking of the fresh fuel as it is first supplied, and further aids the combustion of the volatile gases evolved and thereby tends to prevent smoke.

**54. Playford Chain-Grate Stoker.**—The Playford stoker, which is here shown as a typical example of the chain-grate class, is illustrated in Fig. 28. It consists of a heavy cast-iron frame *e* which is provided with suitable sprocket wheels and rollers on which travels a grate *b b* made up of sections attached to endless chains. The top of the grate is driven slowly toward the rear of the furnace, taking with it coal from the hopper *a*. The amount of coal fed to the furnace is regulated by the speed of the grate and by the

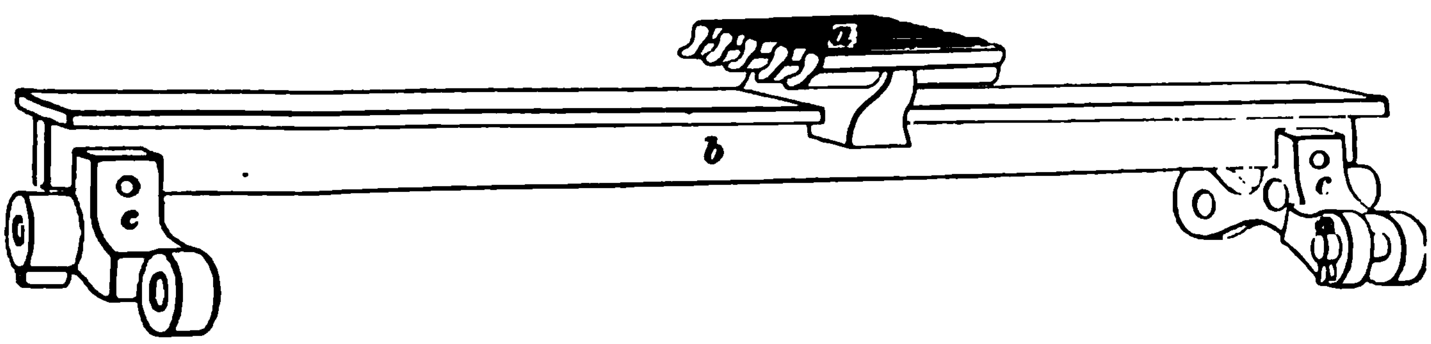


FIG. 29

opening of a gate *d*, which is water-cooled to prevent the heat of the fire from igniting the coal in the hopper. The gas is distilled from the coal in the front of the furnace under the firebrick arch *c* and burns as it rises and passes toward the back. The motion of the grate carries the coke backwards at a rate that permits the carbon to be completely burned before the rear end of the furnace is reached. The ashes and clinkers are dumped into the ash-pit at the back. A spiral conveyer *g* conveys the ashes from the rear of the

furnace to a point near the front or to any convenient point from which they can be removed. The frame *e* rests on rollers that run on rails *f* and make it possible to withdraw the stoker from the furnace when repairs are needed.

In order to make the removal of burned-out grates easy and inexpensive, the grates are made in small sections, as *a*, Fig. 29, which slide over steel **T** bars *b*. The latter are, in turn, easily removed from the chain links *c* by taking out the pins at the ends.

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### UNDERFEED STOKERS

**55.** In order to secure a high temperature of the gas and air, a number of systems of firing have been devised, in which the gas liberated from the freshly fired coal, together with most of the air required for its combustion, are drawn through the bed of burning coke. Such systems, if properly managed, bring the mixture of gas and air into the closest possible contact with the incandescent coke, and, consequently, secure practically perfect and smokeless combustion. The mechanical stokers to which this principle has been applied are known as **underfeed stokers**; the coal is forced by some mechanical device into a magazine or chamber and then through an opening at the top into the bed of burning coke. In this magazine distillation takes place; the coke that is formed in the magazine is forced upwards by the fresh supplies of coal and burns above and at the sides of the magazine. The gas produced meets a supply of air from openings in the sides of the chamber and the mixture arises through the bed of burning coke.

**56.** The **American stoker** illustrates the principles of construction of the underfeed stoker. Fig. 30 shows sectional views of this stoker as applied to a return tubular boiler. Coal is fed into the hopper *a*, from which it is drawn by the spiral conveyer *b* and forced into the magazine *d*, in which it is coked. The incoming supply of fresh fuel forces the coke to the surface and over the sides of the magazine on to the grates *i*, *i*, where it is burned. A blower forces air

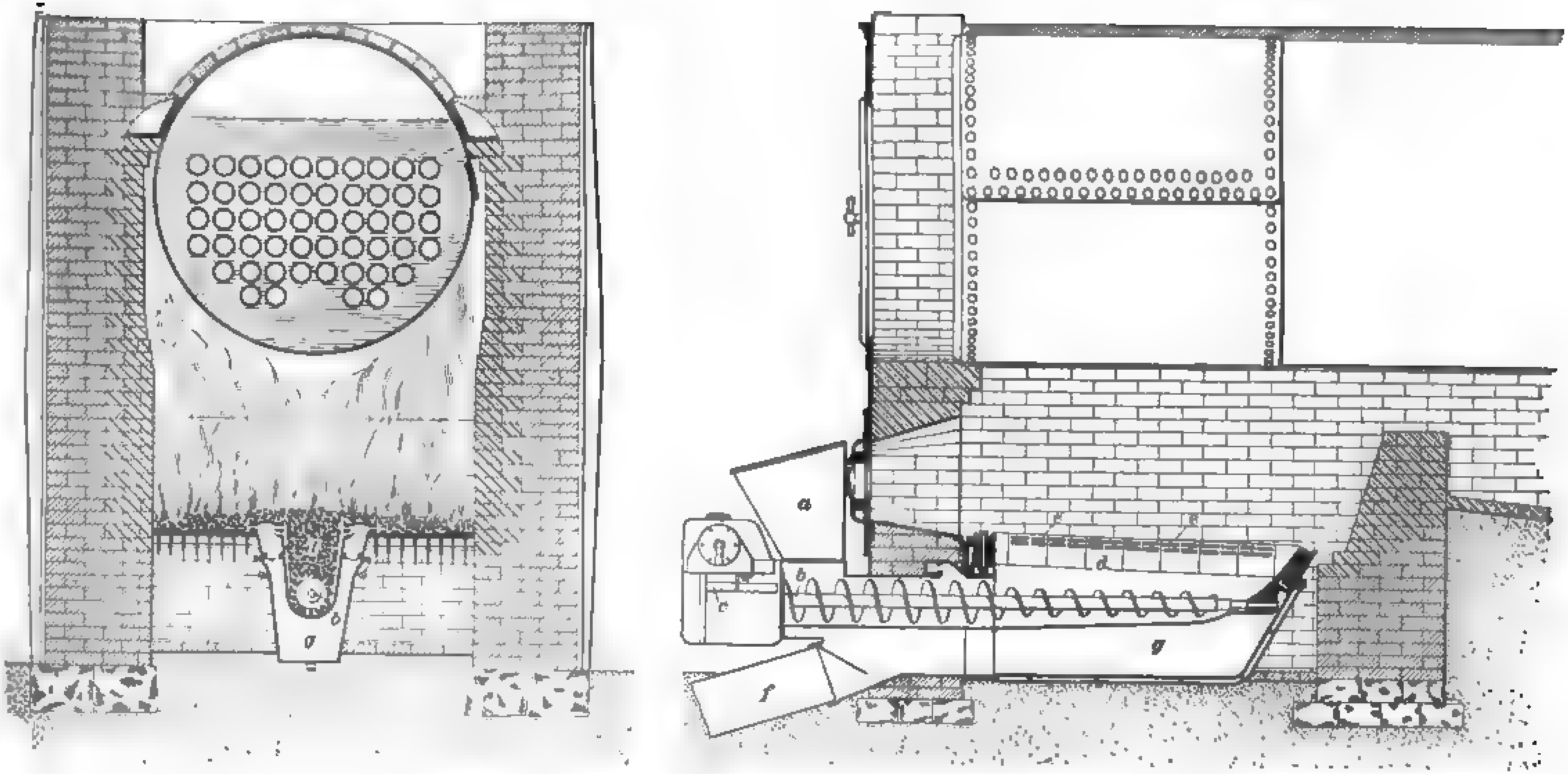


Fig 30

through a pipe *f* into the chamber *g* surrounding the magazine. From *g* the air passes through the hollow cast-iron **tuyère blocks** and out through the openings, or **tuyères**, *e, e, e*. The gas formed in the magazine, mixed with the jets of air from the tuyères, rises through the burning coke above, where it is subjected to a sufficiently high temperature to secure the combustion. Nearly all the air for burning the coke is supplied through the tuyères, only a very small portion of the supply coming through the grate.

The ashes and clinkers are gradually forced to the sides of the grate against the side walls of the furnace, from which they are removed from time to time through doors in the furnace front similar to the fire-doors of an ordinary furnace.

**57.** The construction of this stoker is such that the fire must be cleaned and the ashes removed by hand. This has the disadvantage of a somewhat greater expenditure of labor than is required with those furnaces that discharge their ashes into the ash-pit, especially where it is desired to use ash-handling machinery; it also subjects the boiler to the deleterious influences of inrushes of cold air when the cleaning doors are opened. In this connection it may be stated that it is claimed by the makers that the fires do not need cleaning oftener than once in 8 or 10 hours with the poorer grades of coal, and that once in 12 hours is sufficient with the better grades; it is also a fact that all furnaces require occasional hand stirring and cleaning in order to secure a thoroughly satisfactory distribution of the fire on the grates and to prevent the formation of masses of clinkers that will occasionally stick to the grates, no matter how carefully the stoker is designed and operated.

### ADVANTAGES OF AUTOMATIC STOKERS

**58.** The advantages claimed for automatic stokers over hand firing are: (*a*) The ability to burn a low-grade fuel; (*b*) the prevention of a large amount of smoke from bituminous coal; (*c*) no waste of fuel from cleaning fires; (*d*) an

increase in evaporative capacity of the boilers; (*e*) a uniform supply of fuel and constant high furnace temperature and uniformity of steam pressure; (*f*) a material saving in fuel and labor where large steam boiler plants are used.

There can be no question of these advantages where the conditions are favorable for the use of stokers; these conditions become more apparent with the increasing capacity of the boiler equipment. Reliable tests have shown a saving of from 10 to 20 per cent. in fuel from the use of stokers as compared with hand firing. The lower percentage would be better taken as the basis of estimate for the value of the stoker, and after deducting the cost of repairs it can easily be estimated how long a period would be required for the saving in fuel to pay the cost of the stoker. No saving in labor can be made in a boiler plant of 500 horsepower or less, but in excess of this it may be possible to economize in the number of firemen or helpers.

The whole combination of automatic coal delivery, mechanical stokers, and ash removal by conveyer or cars from a large receptacle below the boiler-room floor, cannot fail to economize in labor and fuel and result in a clean and neat boiler room.

# ELECTRIC POWER STATIONS

## (PART 3)

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## STEAM ENGINES

**1.** Electric power station service, because of very stringent requirements, has been a most important factor in the recent development of types of engines that are far superior to engines of the older classes of construction. The successful engine, be it of any size, type, or speed, must combine the following features:

All parts subjected to strains must be proportioned to withstand higher initial pressures and speeds than engines for commercial manufacturing service. All working parts and wearing surfaces must be very liberal, and also be fitted with the most improved devices for automatic lubrication for continuous service. All bedplates and frames must be exceedingly strong and so proportioned as to maintain perfect alinement. Ample provision must be made for quick and accurate adjustment. All steam passages connecting with the cylinder must be clean cut and so arranged that the entrance of steam into, and its discharge from, the cylinder shall take place with the minimum of loss. The clearance space in the cylinder should be reduced to the smallest possible percentage. The valve gear should be simple, neat, noiseless in operation, having small angles of travel and the moving parts and rubbing surfaces of such metal as will give the maximum amount of durability. The governor must be durable in its construction, highly sensitive in operation, and possess all the regulating qualities described later.

## TYPES OF ENGINES

**2.** The selection of a suitable type of engine is altogether a question of location, service required, and the cost of fuel and water. Engines may be considered under *vertical* and *horizontal types*, and these again subdivided as to speed, and again as *simple* or *compound*, *condensing* or *non-condensing*.

### VERTICAL ENGINES

**3.** Engines of the **vertical type** may be used where real estate is costly and floor space limited. For similar classes of engines the economy is nearly the same, whether the horizontal or vertical type is used; but in attendance and adjustment, the vertical engine will require closer attention. The weight of the piston, piston rod, crosshead, connecting-rod, and boxes will be added to the steam pressure on each descending stroke, and must be deducted therefrom on each upward stroke. Therefore, the work cannot be so uniform as that of the horizontal engine.

### HORIZONTAL ENGINES

**4. Horizontal engines** have the advantage of being wholly under the eye of the engineer from the floor level, the parts are more accessible for adjustment, and in many details the horizontal type is more readily examined, and can be operated with more comfort and less anxiety.

### SIMPLE ENGINES

**5.** This class includes all those engines in which the expansion of the steam is effected in a single cylinder. The **simple engine** is very largely used for small high-speed units or in places where the cost of fuel is of secondary importance. In modern stations of large output, it has been replaced by the compound engine because the increased economy of steam more than offsets the increased first cost of engine. Fig. 1 shows a cross-section of a typical, high-speed, simple engine of the self-oiling type. These engines

are popular for small plants, such as isolated plants in office buildings or hotels, because they have few parts to get out of order and can be run with a minimum amount of attention. The details of self-oiling engines have now been brought to such a high state of efficiency that this feature may be considered reliable when combined with the high standard of work always required in the open engine. High-speed engines of good design have, as individual engines, a wide range of power, which is obtained by the combination of increased or reduced speed, low- or high-steam pressure, and early or late cut-off.

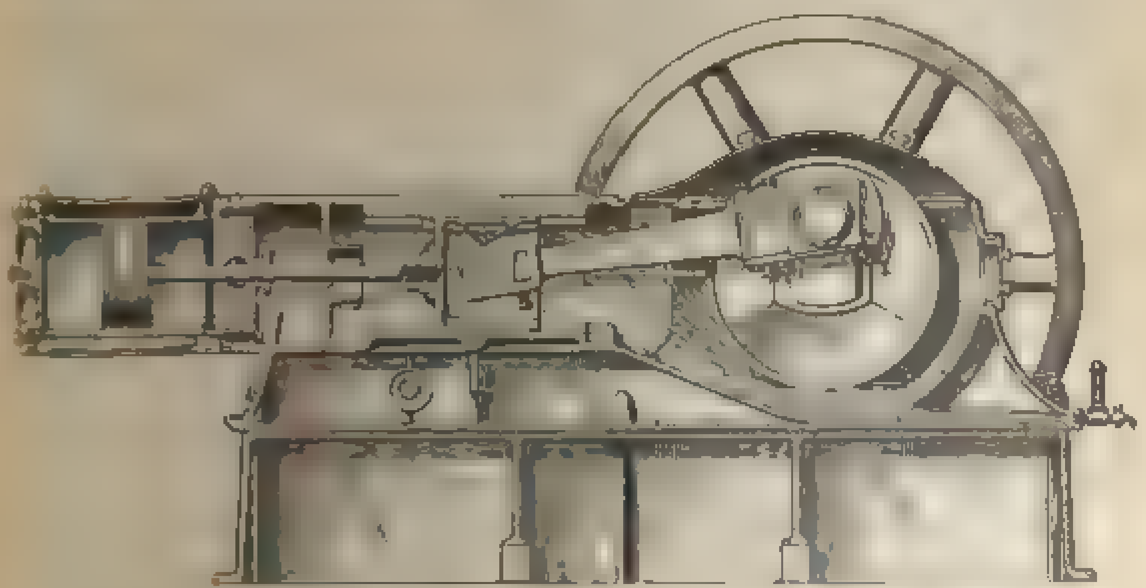

FIG. 1

It has been demonstrated by frequent trials that the favorable point of cut-off in a simple non-condensing engine is at about one-fourth stroke, when using steam at 90 to 100 pounds initial pressure. Cutting off earlier produces a greater percentage of loss through cylinder condensation; cutting off later increases the loss because the steam is exhausted or thrown away while at a considerable pressure.

### COMPOUND ENGINES

**6. Compound engines**, as distinguished from simple engines, are those in which the steam is expanded in two or more stages. The steam is first passed into the *high-pressure cylinder* and there expanded down from boiler pressure

to an amount depending on the design of the engine and the conditions under which it is operated. The steam is then passed into the *low-pressure cylinder* and further expanded, after which it is exhausted into the atmosphere or a condenser, as the case may be. The number of stages in which the expansion of the steam is carried on is denoted by calling the engine a *compound*, *triple-expansion*, or *quadruple-expansion engine*.

**7. Cylinder Condensation.**—An important advantage of compounding lies in the reduced range of temperature occurring in the cylinders, as compared with the range of temperature in the cylinder of a simple engine, using steam between the same limits of pressure as the compound. In a simple condensing engine using steam at an initial pressure of 100 pounds, the entering steam has a temperature of 340° F. If the exhaust pressure is 11 pounds below atmospheric pressure, the escaping steam has a temperature of 150°. The range of temperature in the cylinder is the difference of these figures, or 190°, and this change occurs at every stroke of the engine. Of course, it cannot be said that the iron of the cylinder responds to the above changes to the extent that the figures indicate, but the inner surface of the iron no doubt changes its temperature during each stroke, and at the time of admission its temperature is below the average of the temperatures given. The entering steam, therefore, comes in contact with surfaces whose temperature is far below its own; this causes condensation at those surfaces during admission. During exhaust, heat is transferred to the exhaust steam from the surface of the cylinder. These two actions cause a loss of effect, which is usually stated as that due to **cylinder condensation**. It is greater in amount the greater the range of temperature, and is materially reduced by dividing the expansion into two stages, each being performed in a separate cylinder. In a well-arranged compound engine using steam at the pressures given, the range of temperature in each cylinder will be about one-half as great as in the case of the simple engine, or about 95°.

**8. Arrangement of Cylinders for Compound Engines.**—In considering compound engines, only those engines in which the steam is expanded in two stages will be described. In power-station practice, the triple-expansion engine does not usually give results of sufficiently high economy over a well-designed compound engine to justify the increased expense and complication. Tests made in some cases have actually shown better economy with the intermediate cylinder cut out of service, than with the three cylinders in use. For best economy, the triple-expansion condensing engine must be of large size and operated under a constant load at its best efficiency. This remark applies with greater force to quadruple-expansion engines. Compound engines are usually classed as *tandem compound* or *cross-compound;* either of these types may be horizontal or vertical. A third type which may be classed as *duplex vertical and horizontal compound* has recently been used for larger power-station engines.

**9. Tandem Compound Engines.**—Fig. 2 (*a*) and (*b*) shows two arrangements of the cylinders for tandem compound engines. In this type, the two cylinders are placed in line and there is but one crosshead and connecting-rod. Fig. 3 shows a high-speed tandem compound engine arranged for direct connection to a dynamo. The cylinders are arranged, as in Fig. 2 (*a*), with the low-pressure cylinder *L. P.* next the crank-shaft.

The advantage of the tandem compound engine is its lower cost than the cross-compound engine. Its principal disadvantage is the inaccessibility of the low-pressure cylinder. The cross-compound engine permits a higher rated speed and easier access to both cylinders; it also gives a more uniform turning effort on the crank-shaft. It occupies less floor space in length and greater floor space in width than the tandem compound.

**10. Cross-Compound Engines.**—In these engines the cylinders are arranged side by side, as shown in Fig. 2 (*c*) and (*d*). The steam first passes into the high-pressure

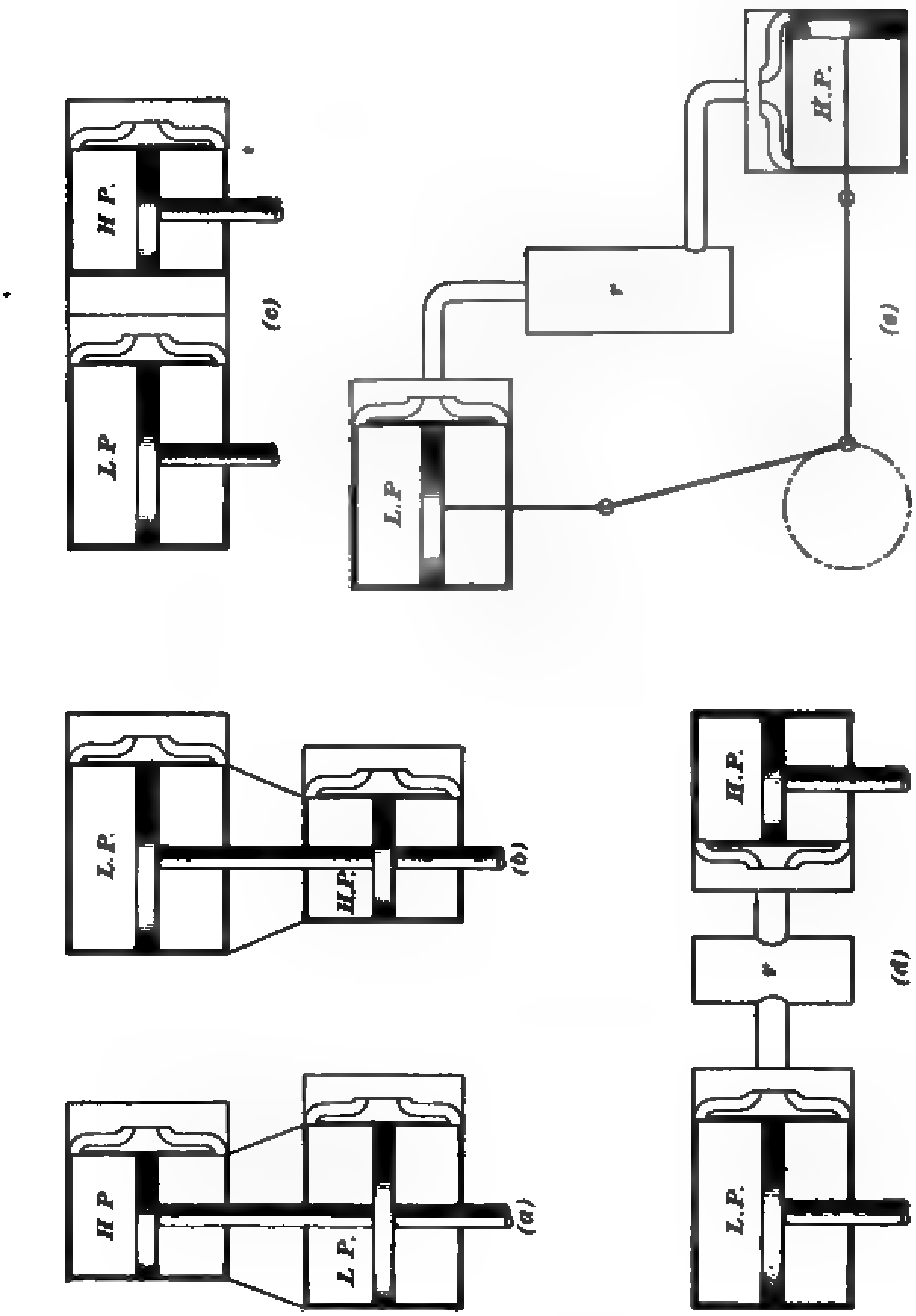


FIG. 2

cylinder *H. P.*, then exhausts into the receiver *r*, if one is provided, and from thence passes into the low-pressure

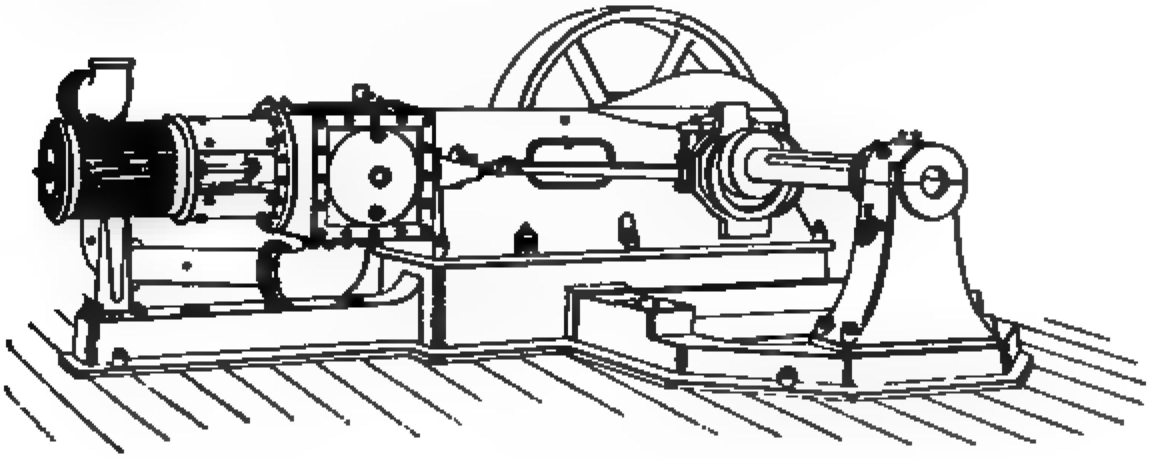

FIG. 3

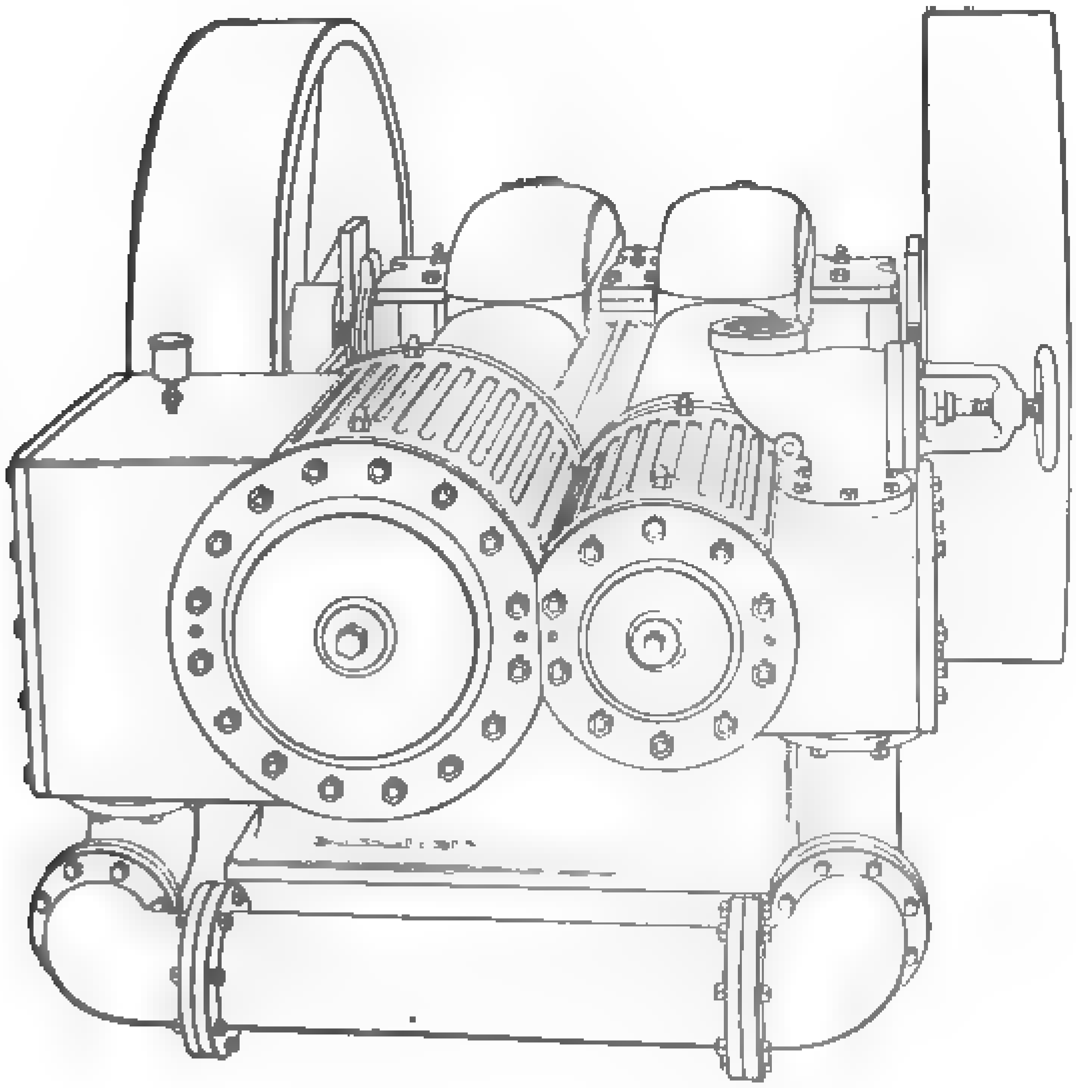

FIG. 4

cylinder *L. P.* The cylinders may be so close together that the receiver *r* forms a jacket connecting the cylinders, or

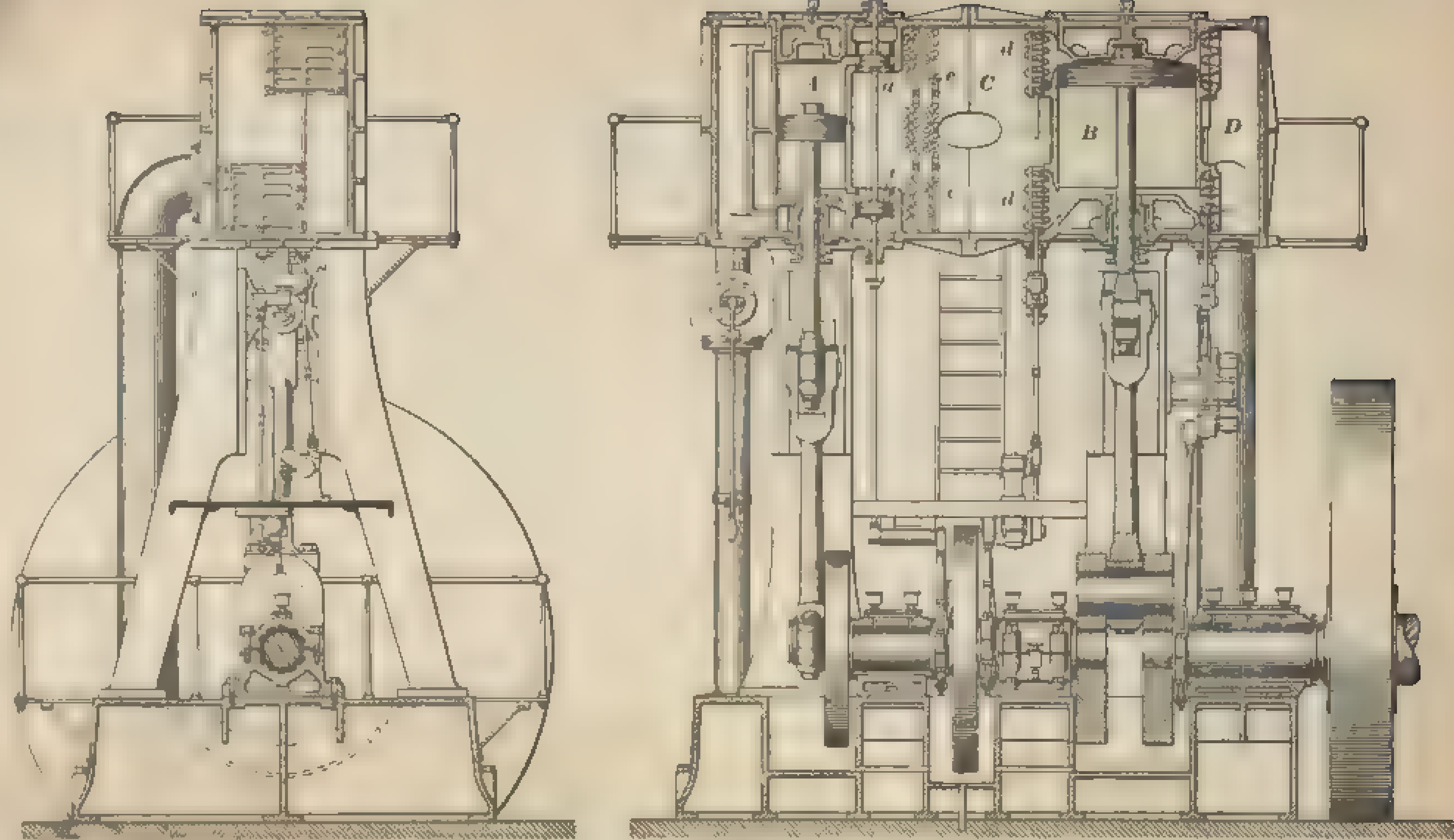

FIG. 5

two distinct engines may be used, as in Fig. 2 (*d*). Fig. 4 shows a rear view of a cross-compound, high-speed engine. Fig. 5 shows a sectional view of a vertical cross-compound engine of moderate size. Steam is admitted to the high-pressure cylinder *A* by means of the piston valves *a*, *a*, which also allow the exhaust to pass into the receiver *C*. From *C*, the steam is admitted into the low-pressure cylinder *B* by the gridiron slide valves *d*, *d*, which give a large port opening with a small range of movement. From *B*, the steam passes into the exhaust chamber *D*, the exhaust being controlled by gridiron valves that are driven independently of the inlet valves *d*, *d*. Each set of valves is driven by an

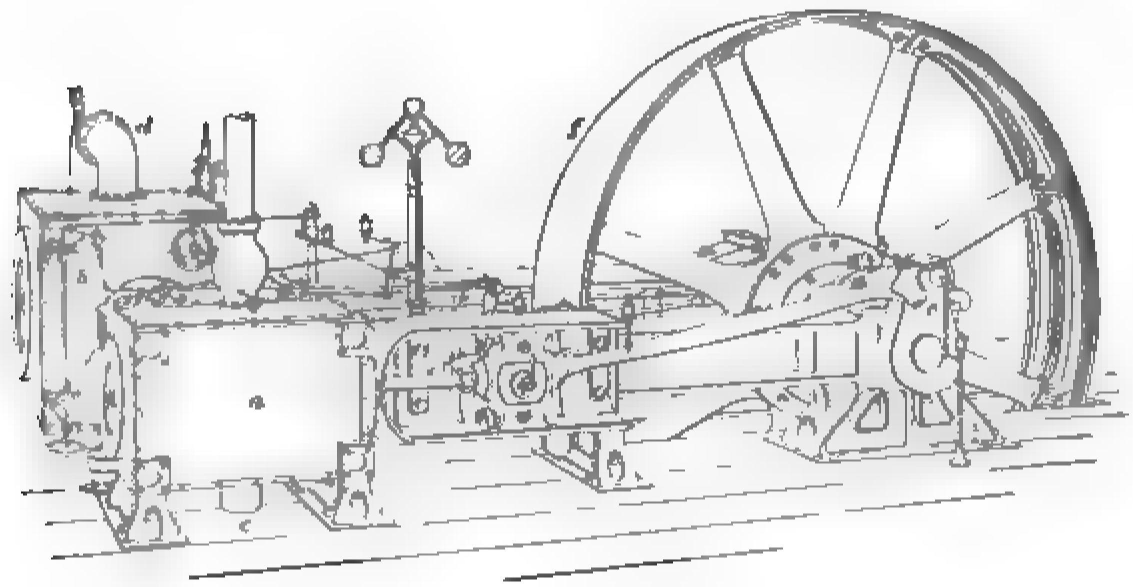

FIG. 6

eccentric on the main shaft. The cross-compound engine gives a more uniform turning effort on the crank-shaft than the tandem compound or simple engine, because the two crankpins used with the cross-compound can be placed at approximately right angles and thereby avoid the dead centers that are always present where only a single crank is used. Fig. 6 shows a horizontal cross-compound engine where the cylinders are separated, thus making in effect two separate engines; *a* is the high-pressure cylinder, *b* the low-pressure, *c* the exhaust from *a* leading to the receiver, and *d* the pipe supplying steam from the receiver to the low-pressure cylinder.

**11.** Fig. 7 shows a type of vertical cross-compound engine that has been used in a number of large electric power stations. It has a Corliss valve gear and is direct-connected to a dynamo, as shown. The steam is led to the engine through the main steam pipe *a* and, before passing into the high-pressure steam chest, flows through a separa-

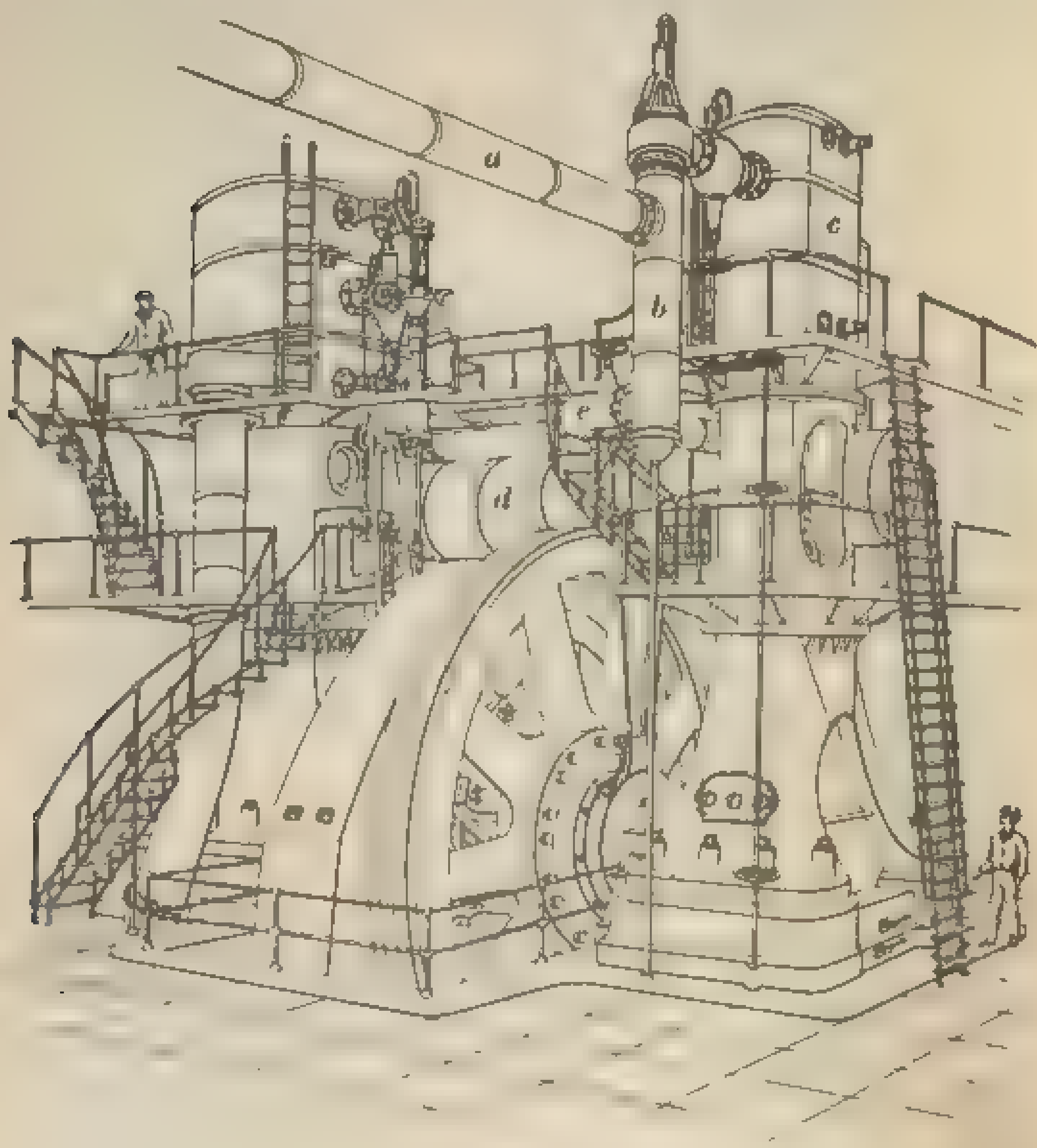


FIG. 7

tor *b*, which removes the entrained water. The exhaust steam from *c* passes into the receiver *d* where it is reheated, as explained later, by live steam taken from the bottom of the separator through the pipe *e*. This particular engine is about 4,500 horsepower, has cylinders 46 and 86 inches in diameter, a stroke of 60 inches, and runs at 75 revolutions per minute.

**12. Duplex Vertical and Horizontal Compound.** Fig. 2 (*e*) shows the arrangement of high- and low-pressure cylinders for this type of engine and Fig. 8 shows one of the engines as built by the Allis-Chalmers Company and used in the power station of the Manhattan Elevated Railway, New York. It consists of four engines, two high-pressure horizontal and two low-pressure vertical, arranged at right angles to each other as shown, *a, a* being the high-pressure cylinders and *b, b* the low-pressure. Each pair of

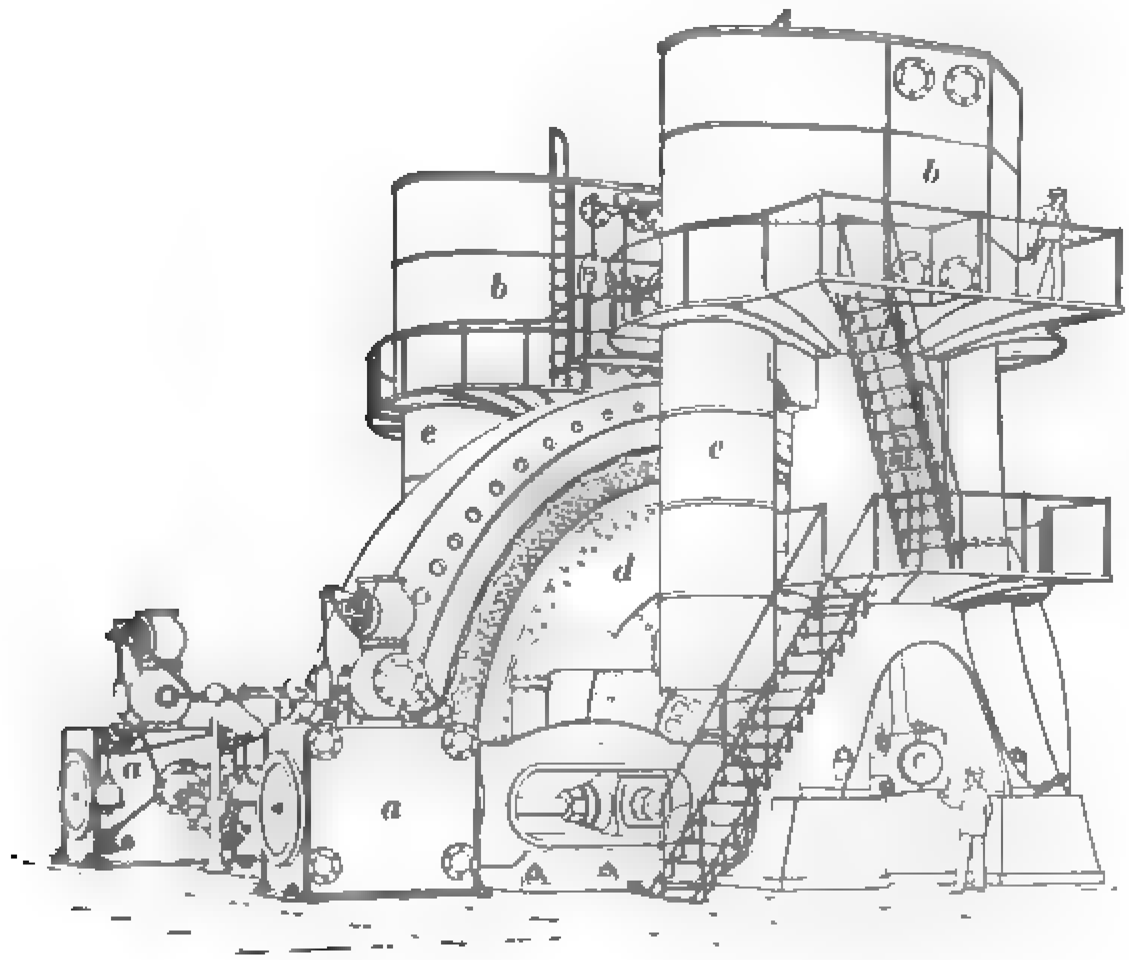


FIG. 8

engines connects to a common crankpin *c*. The cranks of this engine are placed 135° apart, so that the crank-shaft receives eight impulses during each revolution, which gives such a uniform turning effect that the flywheel is dispensed with, its place being taken by the revolving field *d* of the dynamo. The steam from the high-pressure cylinders passes into the receivers *e, e* and thence into the low-pressure cylinders. These engines are of 8,000 horsepower, the

low-pressure cylinders are 88 inches in diameter, the stroke is 60 inches, and the speed 75 revolutions per minute.

**13. Compound Engines Used With Condenser.** The compound condensing engine, when used under favorable conditions of steam pressure and load, is highly desirable, because of its economy of steam. It is not good practice to operate a compound engine without a condenser, for regular service, neither is it good practice to work a compound condensing engine constantly below its rated capacity; because when so operated the amount of steam exhausted from the high-pressure into the low-pressure cylinder is insufficient to do the full work intended for the latter and the engine must drag the low-pressure piston.

Compounding in connection with the condenser renders possible a higher ratio of expansion, either by means of a lower final terminal or a higher boiler pressure, or both, and as the steam is first received in one cylinder and the vacuum formed in another, neither cylinder is exposed to such extreme changes of temperature as when the highest and lowest pressures alternate in the same cylinder. The condensation from internal changes is therefore less, but to realize the most gain, very good external protection from radiation is necessary, as there is increased surface to protect. Compound condensing engines require correspondingly less boiler capacity than simple engines; and this effects a saving in the initial cost of boiler installation as well as maintenance.

**14. Reheaters for Compound Engines.**—Reheaters are frequently used between the high-pressure and low-pressure cylinders of compound engines, to heat the exhaust steam from the high-pressure cylinder before it enters the low-pressure cylinder. Such appliances should be used with caution. It is frequently claimed that there is a liberal percentage of economy gained by the use of reheaters, but it often happens that the reheater is a source of actual loss. This can be readily determined by analysis of the indicator cards showing the work done by the low-pressure cylinder with and without the reheaters in service. Instances are

known where, by actual test of the amount of water of condensation derived from the live steam used to heat the exhaust passing through the reheater, it has been found that the live steam used in the reheater was as much as from 40 to 60 pounds per hour for each horsepower-hour gained in the low-pressure cylinder, whereas the engine itself was operating at a consumption of 17 pounds per horsepower-hour. The location of a reheater *e* is shown in Fig. 5. It consists of a large number of small tubes through which live steam is circulated, thus reheating the steam in the receiver.

## SPEED CLASSIFICATION

**15.** For electric power station service, engines have been classified as *high-speed*, *medium-speed*, and *low-speed*. It is a difficult matter to state where the dividing line between these classes lies, though, roughly speaking, engines running at 200 revolutions or over would be classed as high-speed; from 100 to 200, as medium-speed; and below 100 as low-speed. Electric generators for driving by direct connection to the engine shaft are designed to conform with the rotative speed of the engines. With any generator of given capacity, reduction of rotative speed increases the weight and cost almost in direct ratio, and increase of rotative speed reduces weight and cost. There can be no question, from the practical operative standpoint, that the high-speed engine requires closer daily attention to keep it properly adjusted for good work, and that the cost of maintenance will average a trifle higher than for engines of moderate speed; yet the fact must not be overlooked that electric lighting is indebted to the high-speed engine for its successful commercial development. The low cost of the high-speed engine, its good regulation, and ready adaptability made success possible.

**16. Piston Speeds.** The piston speed limits the length of stroke for a given rotative speed, and is itself limited by the practical mechanical difficulties of lubrication and of successfully reversing the motion at the end of each stroke, of a large mass of metal moving at a very high

velocity. The limits of piston speed for engines of long stroke have been found to be from 700 to 800 feet per minute, and for short-stroke engines, 600 feet per minute. With high-speed engines, the clearance is of a larger proportionate percentage to the volume of piston displacement; this is a disadvantage that pertains to short-stroke engines, but the short stroke permits high rotative speed, thereby reducing the cost per horsepower of the engine and generator, making the unit more compact and requiring the minimum of floor space.

## STEAM CONSUMPTION

**17.** The amount of steam per horsepower-hour required for engines of the different classes, whether vertical or horizontal, is given in tabulated form in connection with Condensers and Condensing Appliances. Regarding steam consumption it is only fair that the steam engine should receive credit for its ability to show the development of an indicated horsepower at a specified economy according to its design and the employment of the necessary auxiliary appliances that make for its economy, but devices extraneous to the engine, which are applied to obtain better economy by recovering heat units that would otherwise be wasted, belong to the plant in the aggregate, and not to the engine as the prime mover. It is not correct to state the economy of steam engines in pounds of coal per horsepower-hour, as this involves the kind and quality of the fuel, the efficiency of the boilers and piping, and the skill of the firemen. The correct expression of engine economy is in terms of the pounds of steam per indicated horsepower-hour per hour, which with single-cylinder non-condensing engines will be 24 to 35 pounds when operated under favorable conditions. The same engines operated condensing will take from 19 to 28 pounds of steam, and compound condensing engines will take 13 to 16 pounds. Finally, to get at the real value of the developed economy, the steam consumption must be calculated down to the pounds of steam per kilowatt-hour developed at the generator. In expressing the economy of steam engines the

terms *steam consumption* and *water consumption* are synonymous. For example, if an engine is said to require 30 pounds of water per horsepower-hour, it is equivalent to saying that it uses 30 pounds of steam per horsepower-hour, because the weight is the same whether the steam is condensed into the form of water or not.

**18. Engine Friction.**—Remembering that the indicated horsepower is greater than the actual horsepower obtained from the engine, it is most important to closely analyze the

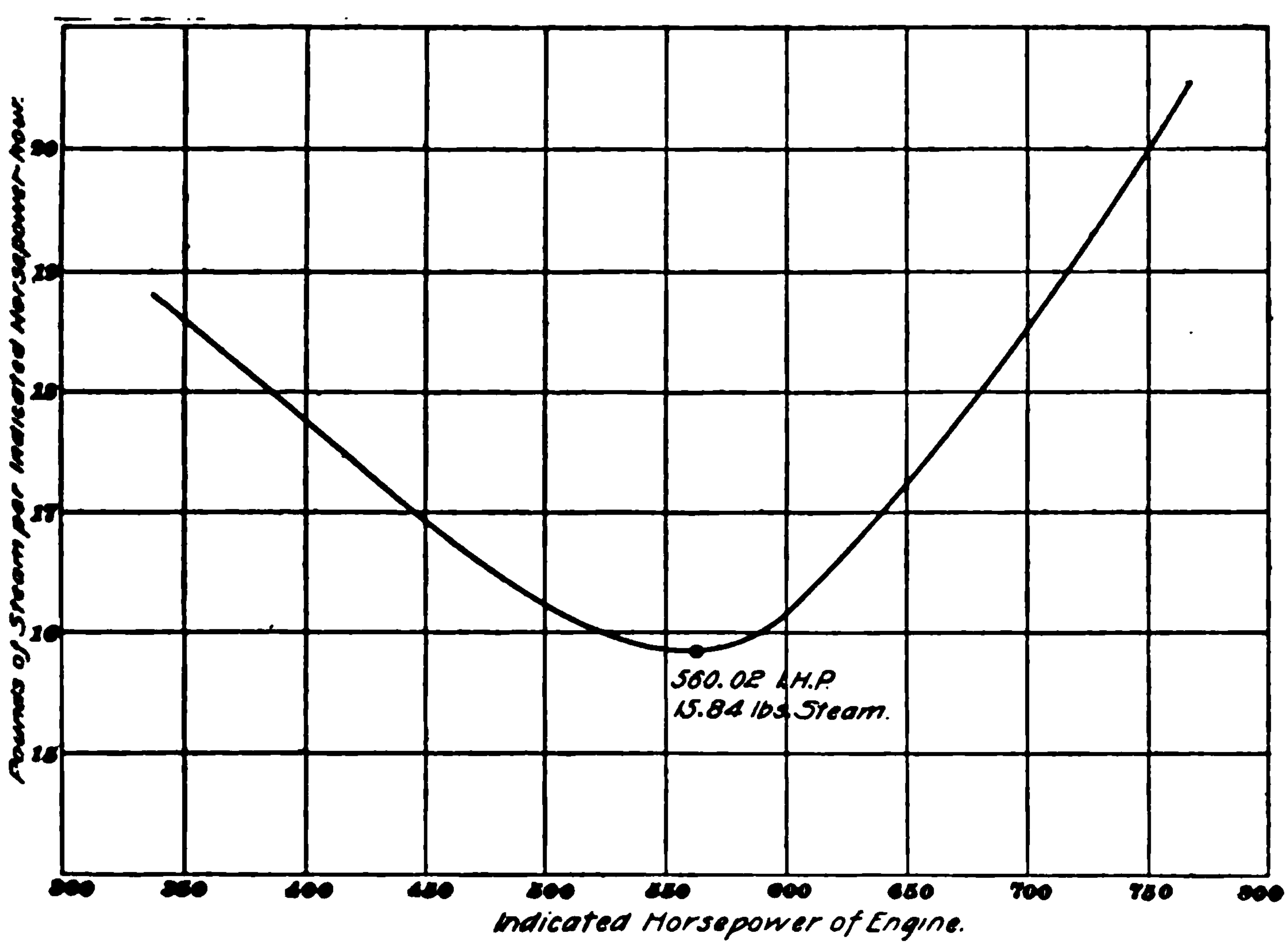


FIG. 9

working parts and to know what the friction indicator card shows, as the engine friction may vary from 6 per cent. to 15 per cent., or possibly more, of the maximum indicated horsepower.

As excessive friction will tend to reduce the commercial efficiency, it is unwise to select engines having complicated valve motions or cumbersome and useless moving parts.

**19. Combined Efficiency of Generating Units.** A point often overlooked is that the engine may be selected too large or too small for the generator. Each engine has a

point of maximum efficiency, which is attained by the combination of the most favorable point of cut-off at a given initial pressure, at which point the indicated horsepower is developed with the minimum of steam consumption. This is illustrated by the efficiency curve shown in Fig. 9, which is derived from a series of tests of a compound condensing engine rated at 600 horsepower, and shows the relation between the indicated horsepower and the steam consumption per indicated horsepower. It is seen that for a load of 560.02 indicated horsepower a minimum consumption of 15.84 pounds of steam per horsepower is reached.

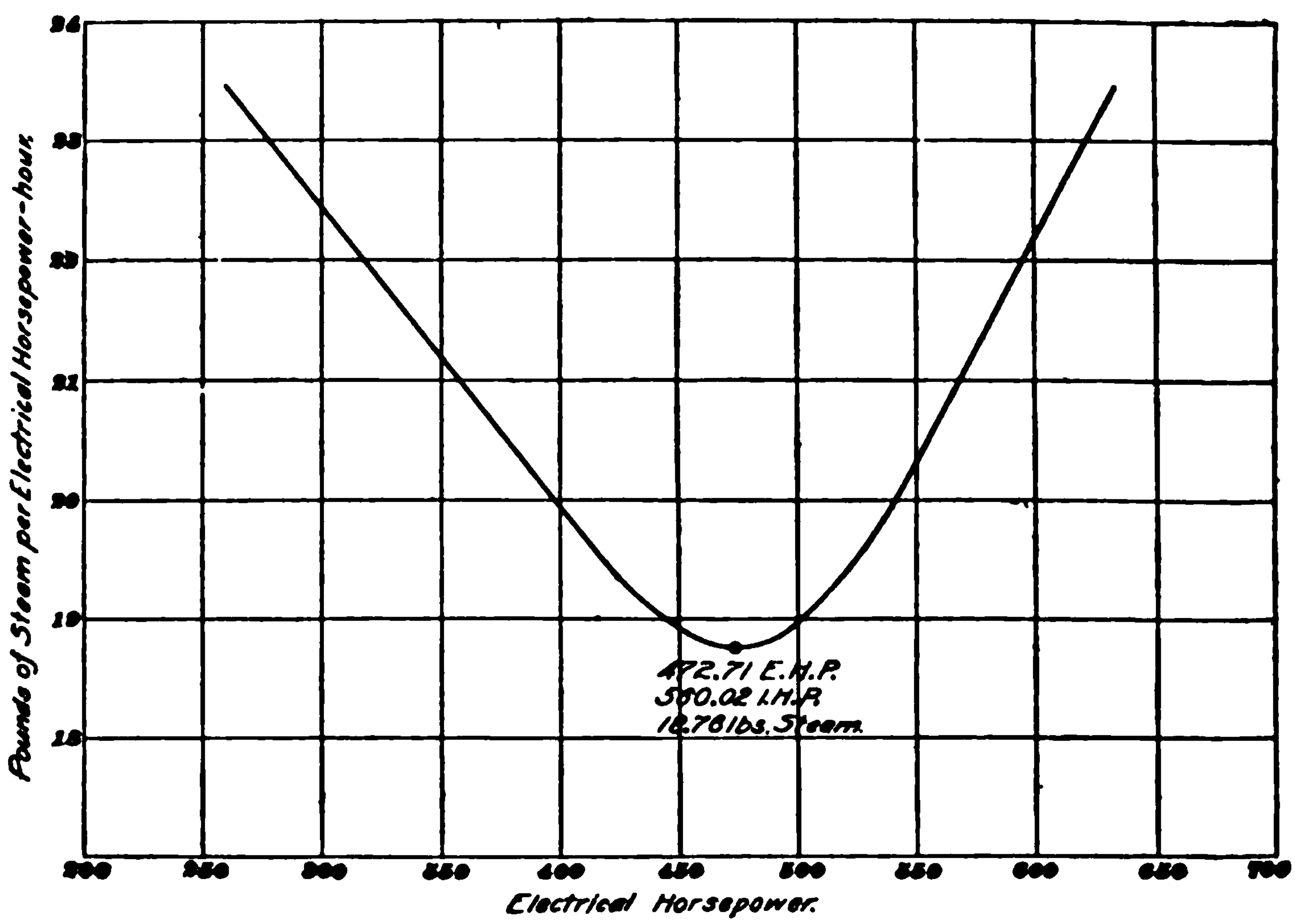


FIG. 10

An electric generator also has its point of maximum efficiency. Now, if the engine and generator as a combined unit are so selected and operated that they reach their points of maximum efficiency simultaneously, it is evident that the unit will show the highest results of its class, indicated by the minimum pounds of steam per electrical horsepower developed.

Fig. 10 shows the relation between the electrical horsepower, delivered at the terminals of the generator, and the

steam consumption per electrical horsepower. Both of these curves show that any considerable departure from the load giving maximum economy results in quite a large increase in the steam consumption per horsepower-hour, and that in order to secure most efficient operation it is necessary to keep the load in the region represented by the lower part of the curves.

## STEAM PRESSURES

**20.** Starting out with what was formerly the customary standard of 75 to 90 pounds boiler pressure, it has been theoretically and practically demonstrated that a higher pressure and earlier cut-off leads to greater economy of steam, so that the pressures now commonly used are 100 to 120 pounds for single-expansion engines, 140 to 160 pounds for compound condensing engines, and 180 to 190 pounds for triple-expansion condensing engines. These higher pressures permit the use of smaller pipes, valves, and fittings than would be required for a similar aggregate horsepower at the low-pressure basis. Thus far it has been found that high-steam pressure should be less than 200 pounds for successful service. The losses, annoyances due to unexpected leakage, difficulties of engine lubrication, wear and tear, and repairs, thus far offset the gain theoretically to be obtained from any higher pressures. Improvements are constantly being made to perfect the satisfactory use of still higher pressures, which may be particularly adapted for very large stations.

## DESIRABILITY OF SEVERAL ENGINES

**21.** In a power station having a variable load, such as incandescent lighting, the best engine economy is attained when the engine units are selected of such capacities and duplicated, so that as the load increases or decreases the engine units may be put in or taken out of service; and each engine while in service shall be operated at its highest efficiency during the greatest possible number of hours.

The capacity, type, and speed of engines to be selected

for a given station can best be determined by careful consideration of the following points:

1. The character of the load, whether for incandescent lighting, arc lighting, motive power, electric railways, or a combination of part or all.

2. The probable area of the load diagram, and the fluctuations in the load line.

3. The cost of fuel for steam production, the cost of real estate, etc.

4. The location of the station as regards water supply for condensing purposes, coal delivery, ash haulage, etc.

As to whether the units of engines and generators shall be direct-connected or belt-driven, the selection for the smaller station is frequently and non-scientifically decided in favor of the belt-driven, because of a few hundred dollars extra investment required for the direct-connected unit, often losing sight of the cost of the extra floor space required, belt maintenance, loss by friction, and similar expense occasioned by the use of belt-driven apparatus.

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## STANDARD DIMENSIONS AND SPEEDS FOR DIRECT-CONNECTED ENGINES AND GENERATORS

**22.** In order that, as far as practicable, standard dimensions may be adopted by builders of engines and generators for combination as direct-connected units, a committee of the American Society of Mechanical Engineers have, after full investigation and consultation, recommended the capacities, speeds, and dimensions shown in Table I and Fig. 11. These recommendations refer to generating units made up of a high-speed engine coupled to a dynamo mounted on a sub-base that forms an extension of the engine bed, as in Fig. 3. The size of units does not exceed 200 kilowatts, and the schedule provides for a variation of 5 per cent. above or below the mean speed. The dimensions of shafts apply only to engines of usual proportions with the generators attached at the side of the engine. Two styles of generators are

TABLE I

SIZES, SPEEDS, AND STANDARDIZED DIMENSIONS OF DIRECT-CONNECTED GENERATING SETS

| Capacity of Unit Kilowatts | Revolutions per Minute | Armature Bore Inches: Center-Crank Engines | Armature Bore Inches: Side-Crank Engines | Diameter of Engine Shaft at Armature Fit Inches: Center-Crank Engines | Diameter of Engine Shaft at Armature Fit Inches: Side-Crank Engines | Space on Shaft Between Limit Lines Inches: Long Class A | Space on Shaft Between Limit Lines Inches: Short Class A' | B, Length of Extension Pieces Inches | C, Axis of Shaft Above Top of Base Inches | E Inches | D, Width of Top of Subbase Inches | Key (a Feather) Inches: Width | Key (a Feather) Inches: Thickness | Key (a Feather) Inches: Depth in Shaft at Edge | Key (a Feather) Inches: Projection Above Shaft at Edge | Holding-Down Bolts: Diameter Inches | Holding-Down Bolts: Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 25 | 310 | 4 | 4½ | 4 + 0.001 | 4½ + 0.001 | 30 | 25 | 5 | 23½ | Flat | 48 | 1 | ¾ | ⅜ | ⅜ | 1 | 4 |
| 35 | 300 | 4 | 5½ | 4 + 0.001 | 5½ + 0.001 | 33 | 28 | 5 | 25 | Flat | 54 | 1 | ¾ | ⅜ | ⅜ | 1 | 4 |
| 50 | [illegible] | 4½ | 6½ | 4½ + 0.001 | 6½ + 0.002 | 37 | 31 | 6 | 28 | Flat | 60 | 1¼ | ¾ | ⅜ | ⅜ | 1 | 4 |
| 75 | 275 | 5½ | 7½ | 5½ + 0.001 | 7½ + 0.002 | 43 | 37 | 6 | 31 | Flat | 66 | 1¼ | 1 | ½ | ½ | 1¼ | 4 |
| 100 | 260 | 6 | 8½ | 6 + 0.001 | 9½ + 0.002 | 45 | 42 | 6 | 34 | Flat | 72 | 1½ | 1 | ½ | ½ | 1¼ | 4 |
| 150 | 225 | 7 | 10 | 7 + 0.002 | 10 + 0.002 | 51 | 45 | 6 | 37¾ | 41¼ | 84 | 1¾ | 1¼ | ⅝ | ⅝ | 1¼ | 4 |
| 200 | 200 | 8 | 11 | 8 + 0.002 | 11 + 0.002 | 54 | 48 | 6 | 42¾ | 47½ | 96 | 2 | 1¼ | ⅝ | ⅝ | 1½ | 4 |

NOTE 1.—Five per cent. variation of speed permissible above and below speeds in table.

NOTE 2.—Distance from center of shaft to top of base of outboard bearing may be less than $C$ (to suit engine builder), though not less than possible outside radius of armature.

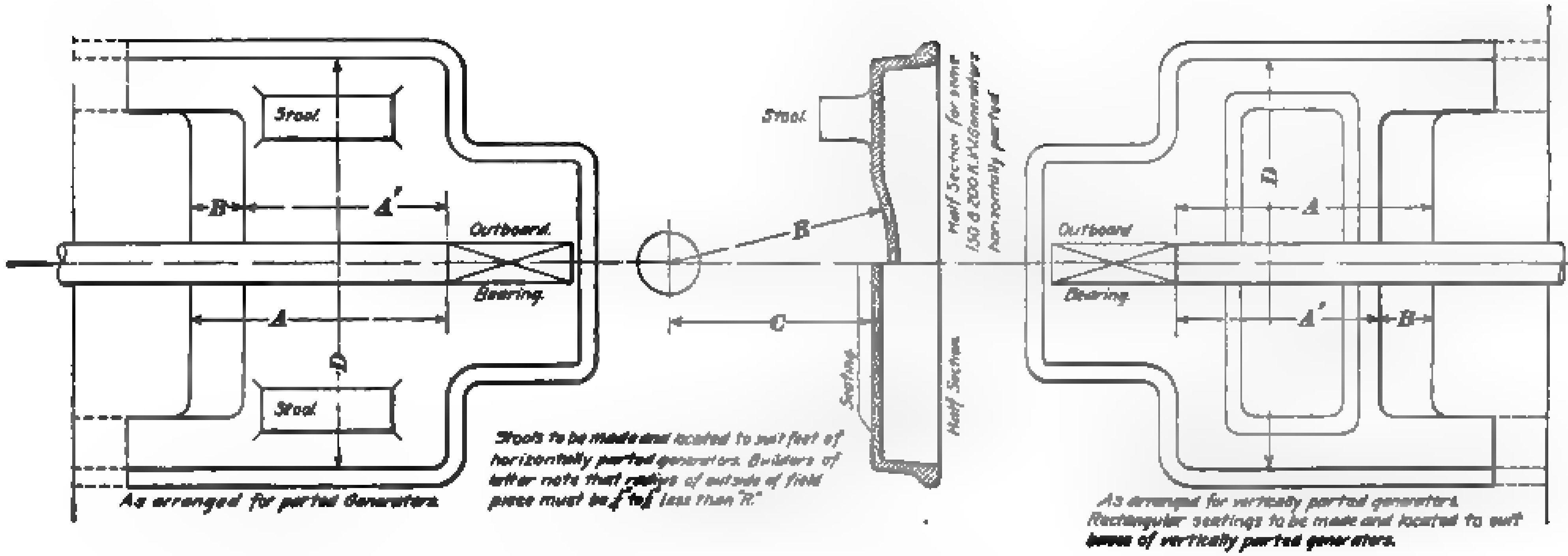
Stool
Outboard
Bearing
Stool
Half Section for same
150 & 200 K.W. Generators
horizontally parted
Seating
Half Section
Stools to be made and located to suit feet of
horizontally parted generators. Builders of
latter note that radius of outside of field
As arranged for parted Generators.
As arranged for vertically parted generators.
Rectangular seatings to be made and located to suit
bases of vertically parted generators.

Fig. 11

provided for—those having the fields divided vertically and those having the fields divided horizontally. Seatings for each style of machine are provided by two patterns of extension subbase for the generator. The overload capacity should not exceed 25 per cent. of the rated capacity for 2 hours, or 50 per cent. for 30 minutes.

**23. Armature Fit.**—The bore of the armature is to be the exact size stated in the table; the allowance for a pressed fit is to be made by a slight increase in the diameter of the engine shaft. The allowance of .001 inch for shafts of 4 to 6 inches, inclusive, and of .002 inch for shafts $6\frac{1}{2}$ to 11 inches, inclusive, represent the best practice. The best results will be attained by working to a definite gauge; and the generator builder should be required to furnish one of the exact diameter of armature bore, and the engine builder will make due allowance for a pressed fit.

Holding down bolts, keys, and outboard bearings should be furnished by the engine builder. The length of key is to be adjusted between the builders of engine and generator in each individual case, and it should be specified in the contract which builder shall fit and press the armature on the shaft. For engine and generator units of other types and larger capacity, the specifications should clearly set forth the particular details required for each manufacturer on all of the above points, to the end that there shall be no clash of opinion or division of responsibility, and also that the purchasing company shall not be put to unexpected extra expense by the failure to specify clearly these matters in advance.

## ENGINE REGULATION

**24. Flywheels.**—In reciprocating engines, the elements that disturb regulation are variations of load and the engine impulses. The following factors have their influence on the uniformity of rotative effect during each revolution of the shaft:

1. The weight and momentum of the reciprocating parts,

which are the piston and piston rod, the crosshead, and connecting-rod.

2. The mean effective steam pressure on the piston.

3. The inertia of the reciprocating masses that must be overcome at each end of the stroke.

In vertical engines, the conditions are different from horizontal engines, as in the vertical engine the weight of the reciprocating parts acts on the downward stroke the same as an equal amount of steam pressure, adding to the work done; and, correspondingly, the same force must be subtracted from that of the up stroke, as these weights must then be lifted. This makes a difference in the power of each stroke. Allowance must also be made for the influence of the different positions of the connecting-rod, which influence is different in vertical and horizontal engines.

To overcome these disturbing influences, the flywheel is mounted on the engine shaft with the purpose that the heavy rim shall aid in maintaining a certain degree of uniformity in angular velocity during each engine revolution. For electric power station service, it is necessary, not only that the number of revolutions per minute should be practically constant within narrow limits, but, particularly for driving alternating-current generators in parallel, it becomes vitally essential that the variation of angular velocity during each revolution shall be confined within exceedingly narrow limits. It is for this reason that the rim of the flywheel, which is the only revolving mass having any influence on the regulation, must be of sufficient weight to provide the momentum requisite to overcome not only the influences of the reciprocating parts that are operating against uniformity of rotation, but also variations in the retarding effects of the work done by the revolving element of the generator.

**25.** The commercial requirements for the governing of engines for electric service, are now sufficiently well known for first-class engine builders to guarantee the required regulation. From the nature of the power-station service, the load is continually changing. Any variation in engine

speed causes disturbances on the system, and it is therefore essential that the speed shall be uniform during all changes of load; and even under variations of boiler pressure, say for 5 pounds above or below normal, there should not be any disturbance on the system.

The governor must regulate to a high degree of perfection with very rapid adjustment, and without the slightest instability or tendency to race. The modern inertia governor is well adapted for this service. In a well-designed governor of this type, the resisting strains will be so well equalized as to balance each other and not cause any excessive strain on the studs or bearings of the governor. The engines must not race under any conditions of service and must be so governed as to permit the generators to be operated individually or in parallel with each other.

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### REGULATION FOR ALTERNATING CURRENT

**26.** Engines for driving alternating-current generators require closer regulation than those driving direct-current generators. Definite conclusions have not yet been reached concerning the exact changes that take place in operating alternating-current machines in parallel. It is essential, however, that they run with sufficient regularity not to get out of phase with each other. In other words, they must remain in step. In addition to the steadying effect of the flywheel, the control of the steam admitted to the engine must be so well regulated that the flow shall not be in excess of that needed in combination with the stored energy in the flywheel; therefore, as power cannot be obtained from the engine without the requisite quantity of steam, the admission of steam must be controlled by a governor sufficiently sluggish in its action to prevent periodic pulsations; this is best accomplished by a proper dashpot arrangement attached to the governor.

**27.** The parallel operation of polyphase alternators driven by well-regulated turbine waterwheels has been uniformly successful, undoubtedly because the turbine wheel is not

forced to overcome the tangential effort of the crank-movement and the reversal of heavy reciprocating parts twice during each revolution, as is the reciprocating engine. The governors of engines used to drive alternators should be so designed and constructed that there will be no tendency to cause a periodic transfer or surging of the load between one engine and another, as surging is similar to throwing the load quickly off or on a single engine at short intervals. The natural function of the governor is to regulate the supply of steam in proportion to the load, and for the satisfactory driving of alternators the natural tendency of the governor to perform its task quickly must be overcome by attaching a dashpot, or some form of friction brake, to prevent the governor from responding too quickly to changes in load, or with small changes give no response at all. The use of governors that are adjustable while running is desirable, and a motor adjustment controllable from the switchboard is commonly provided.

The variation of the rotative speed of the generator during any single revolution at constant load not exceeding 25 per cent. overload should not exceed one-sixtieth of the pitch angle between two consecutive poles from the position it would have if the rotative motion were absolutely uniform at the same mean velocity. The maximum allowable variation, which is the amount the rotating part forges ahead plus the amount that it lags behind the position of uniform rotation, is therefore one-thirtieth of the pitch angle between two poles. According as the number of poles on the alternator increases the permissible angular variation decreases, as shown by Table II.

Where several engines are located in one station to drive alternators in parallel, they should have the same characteristics of speed regulation to the end that the power delivered to their respective generators may be proportional to the load.

**28.** In some cases where parallel operation is possible, the angular variation may be such that the operation of

rotary converters or synchronous motors is unsatisfactory. If the engines in the station are set in such perfect alinement that it is possible to look through the spokes of the flywheels, it is easy to see the change in relative angular position when the several engines are in operation. It is important that the governors shall be fully competent to control the engines under all changes of load, from no load to 25 per cent. or 50 per cent. overload, when operating the generators in parallel; and that as the load rises to the maximum or falls to the minimum, the governor shall permit the load to be shifted from engine to engine, to the end that the engines may be taken out of or put in service and be loaded to the most economical point of operation.

TABLE II

MAXIMUM PERMISSIBLE ANGULAR VARIATION OF ENGINES DIRECT-CONNECTED TO ALTERNATORS

| Poles | Angular Degrees | Per Cent of Circumference | Poles | Angular Degrees | Per Cent of Circumference |
|---|---|---|---|---|---|
| 2 | 3.000 | .833 | 40 | .150 | .042 |
| 4 | 1.500 | .417 | 44 | .136 | .038 |
| 6 | 1.000 | .278 | 48 | .125 | .035 |
| 8 | .750 | .208 | 52 | .115 | .032 |
| 12 | .500 | .139 | 56 | .107 | .030 |
| 16 | .375 | .104 | 60 | .100 | .028 |
| 20 | .300 | .083 | 64 | .094 | .026 |
| 24 | .250 | .069 | 68 | .088 | .025 |
| 28 | .214 | .059 | 72 | .083 | .023 |
| 32 | .187 | .052 | 76 | .079 | .022 |
| 36 | .167 | .046 | 80 | .075 | .021 |

Specifications of requirements of engine regulation and guarantees of performance cannot be drawn too carefully, and the engine builder must be one who understands from a practical standpoint the detrimental results of defective regulation and from experience knows how to furnish what is required. The object of the peculiar specification as to

engine regulation for driving alternators in parallel is to limit the amount of cross-currents that can flow between the generators and prevent troubles with synchronous apparatus, such as synchronous motors and rotary converters. This whole matter is one in which no risk can be taken with engine builders of doubtful experience.

The weight of the flywheel should be such that its momentum will not permit one machine to drag behind the other, and the amount of variation either way in the angular velocity in a single revolution should not exceed one-sixtieth of the pitch angle between two consecutive poles. In a 24-pole alternator, for example, the angle between poles would be $\frac{360}{24}$ and the allowable variation either way would be $\frac{1}{60} \times \frac{360°}{24} = \frac{1}{4}°$, or .0693 per cent. of a revolution. Under any change of load, therefore, the internal variation of speed will not exceed one quarter of one geometrical degree from the position of uniform rotation during any single revolution.

## STEAM TURBINES

**29.** In principle, the **steam turbine** is not new, as its type is the first heat motor of which we have record. It dates from as far back as 120 B. C. The apparatus of Hero of Alexandria, was a reaction turbine and is described as a spherical vessel mounted on trunnions through which steam was admitted to issue finally from openings tangential to the sphere, the reaction of the steam jets causing the sphere to revolve. The steam turbine, in recent years, has been modified and improved to such a degree that in future power-station equipments, it will be a strong rival of the reciprocating engine. It is in many ways particularly well suited for the driving of dynamos and is now being installed in many new power stations.

**30.** In the steam turbine, the steam is made to produce rotary motion by causing jets to act on a suitably arranged wheel, or series of wheels, carrying vanes or buckets. The energy stored in the steam is thus made to produce a uniform

rotary motion of the turbine shaft and the intermediate reciprocating motion of the ordinary engine is eliminated. Early types of steam turbine were very wasteful of steam and thus were not able to compete with the reciprocating engine. Improvements, however, have been made until now the turbine is at least as economical, if indeed not more economical than the reciprocating engine. The pressure or expansive force of the steam delivered to the steam turbine is caused first to act on the steam itself, thus generating velocity in the jet, which is directed on the blades of the turbine, and the energy of the steam thus transferred thereto.

In a waterwheel it is clear that the wheel is turned by the impact or pressure of a heavy mass of water having density and substance to cause the revolutions. The steam makes up in velocity what it lacks in mass. A jet of water 1 inch in diameter issuing at a pressure of 100 pounds per square inch will discharge 41 pounds per second at a velocity of 121 feet per second, representing, approximately, 9,300 foot-pounds of work per second.* This amount of work expended per second on a turbine wheel (if one of 100 per cent. efficiency) will generate about 17 horsepower. A jet of steam issuing through an orifice 1 inch in diameter, under 100 pounds gauge pressure, will deliver 1.293 pounds of steam per second at a velocity of 1,466 feet per second. If this steam is allowed to strike against a wheel so that the whole of the kinetic energy of the jet is converted into power, the jet can do, approximately, 43,200 foot-pounds of work per second. Since 1 horsepower is equivalent to 550 foot-pounds per second, the jet will be able to deliver $\frac{43200}{550} = 78.5$ horsepower. The amount of steam delivered per hour will be $1.293 \times 3,600 = 4,654.8$ pounds, equivalent to nearly 59.3 pounds of steam per horsepower-hour.

In the above example relating to a steam jet it should be noted that the steam is supposed to blow through a plain orifice and impinge on the wheel to which it imparts

*Kinetic energy = $\frac{1}{2}$ mass $\times$ velocity$^2$ = $\frac{1}{2} m v^2 = \frac{1}{2} \frac{W}{g} v^2 = \frac{1}{2} \times \frac{41}{32.16} \times (121)^2 = 9,332$ foot-pounds.

energy due to the velocity of the steam as it passes through the orifice. By suitably arranging the nozzles or turbine wheels so that the steam is allowed to expand, a considerable part of the heat energy stored in it can be made available, thus materially reducing the steam consumption per horsepower-hour. Thus, in the nozzle of the De Laval turbine the steam expands until, when it strikes the wheel, it is at practically the same pressure as the steam in the chamber in which the wheel revolves. A large part of the heat energy stored in the steam is thus given up during the process of expansion and goes to increase the velocity. A velocity of over 4,000 feet per second can be obtained in this manner; and since the energy increases with the square of the velocity, the steam consumption per horsepower can thus be greatly reduced from the amount given in the above example, which merely compares a steam jet with a water jet.

All successful types of steam turbine make provision for this expansion of the steam to increase its velocity. In the De Laval turbine, the expansion takes place wholly in the nozzles and the steam is delivered to the buckets at a low temperature and pressure but at a very high velocity. In the Curtis turbine, the steam is expanded partly in the nozzles and partly during its progress through the turbine wheels, the continuous expansion and consequent abstraction of heat energy from the steam keeping up the velocity until the steam is finally discharged from the last wheel at the temperature and pressure corresponding to the degree of vacuum in the condenser. In the Parsons turbine, the steam is expanded during its passage through the turbine and is not expanded in the inlet nozzles.

## TYPES OF STEAM TURBINES

**31.** The three most important types of steam turbines at present manufactured in the United States in competition with reciprocating engines, are the De Laval, manufactured by the De Laval Steam Turbine Company; the Parsons, manufactured by the Westinghouse Company; and the Curtis,

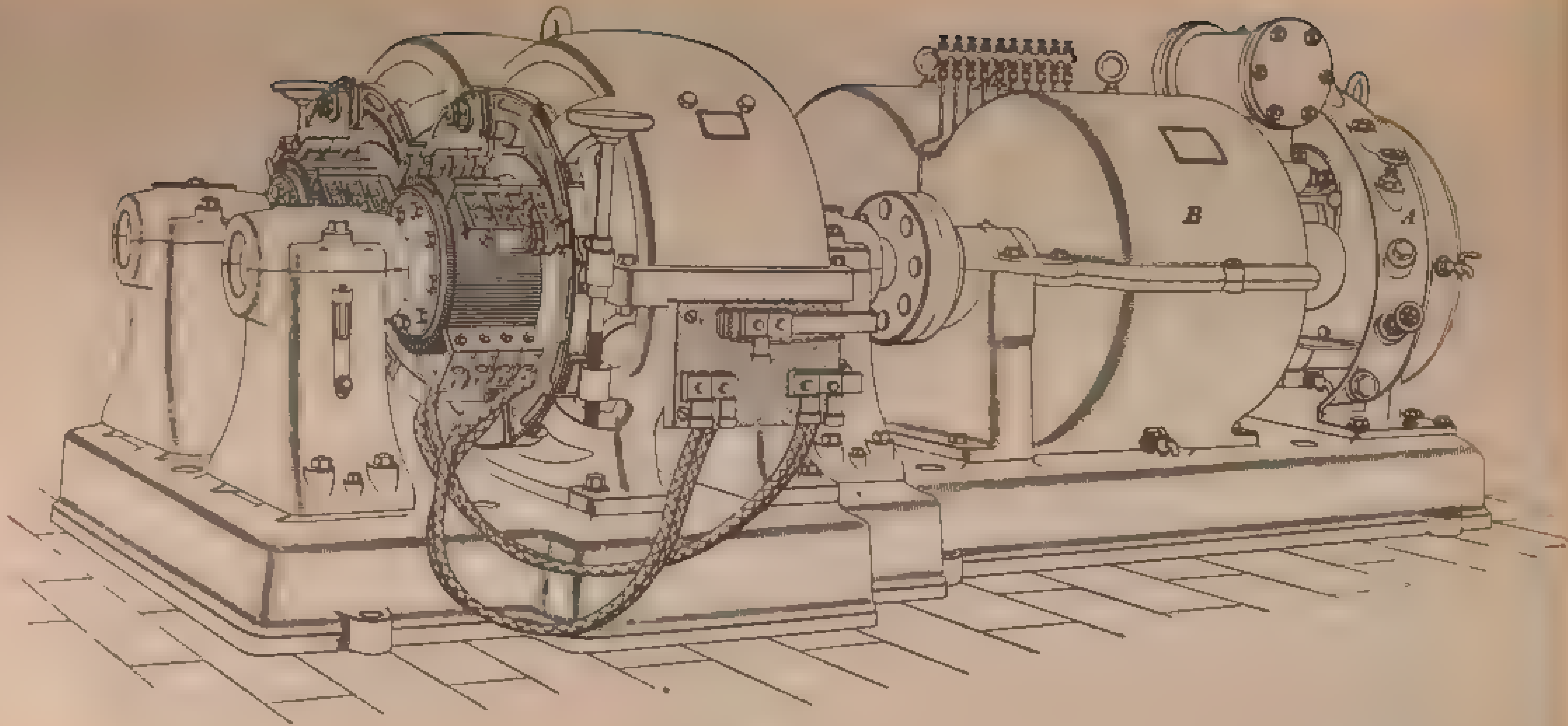


FIG. 12

manufactured by the General Electric Company. The principles of operation of these turbines have been described elsewhere. The Parsons and Curtis turbines run at a comparatively low rotative speed and can therefore be direct-connected to dynamos; while the De Laval is essentially a high-speed machine and is connected to the dynamo through special gearing. Turbines are particularly well suited to the driving of alternators, since the latter can be readily designed for high rotative speeds, especially if the revolving field construction is used. It is more difficult to construct direct-current machines of large output for high rotative speeds, because the extremely rapid reversal of the current in the armature coils during the time they are passing through the neutral region makes it difficult to secure sparkless commutation. Moreover, the mechanical difficulties at the commutator are liable to increase with the speed.

**32. De Laval Turbine-Dynamo Set.**—Fig. 12 shows the general arrangement of a De Laval turbine as applied to the driving of two direct-current dynamos. The turbine wheel is in case *A* while case *B* contains spiral gears running in oil and driven in similar directions by a spiral pinion mounted between them. Each dynamo is of 100 kilowatts capacity, so that the turbine develops, approximately, 300 horsepower. The whole outfit occupies a floor space only 6 feet 3 inches by 15 feet.

The loss of efficiency caused by friction in this type of turbine is claimed to be much below that of a compound reciprocating engine, and the steam consumption per horsepower-hour is almost uniform from one-quarter load to 25 per cent. overload. Under test, it is claimed that this turbine showed the use of 15.43 to 15.99 pounds saturated steam per brake horsepower-hour, and with steam superheated 84° F. it required from 13.55 to 14.21 pounds of steam per brake horsepower-hour, the saving by the use of superheated steam being about 8½ per cent.

**33. Parsons Turbo-Alternator.**—Fig. 13 shows a 1,000-kilowatt set consisting of a turbine coupled to a

polyphase alternator. The steam enters at *a* and passes through the governing valve *b* and from thence between the sets of stationary and revolving blades contained in casing *c*. From *c* the steam passes to the set of blades contained in casing *d* and from thence exhausts into the condenser. The steam passes through the turbine in an axial direction, and between *c* and *d* it may be passed through a reheater. The arrangement of the blades in two distinct casings corresponds in a way to the high- and low-pressure cylinders of a compound engine. Means are provided for forced lubrication of the bearings, oil being circulated by means of a pump

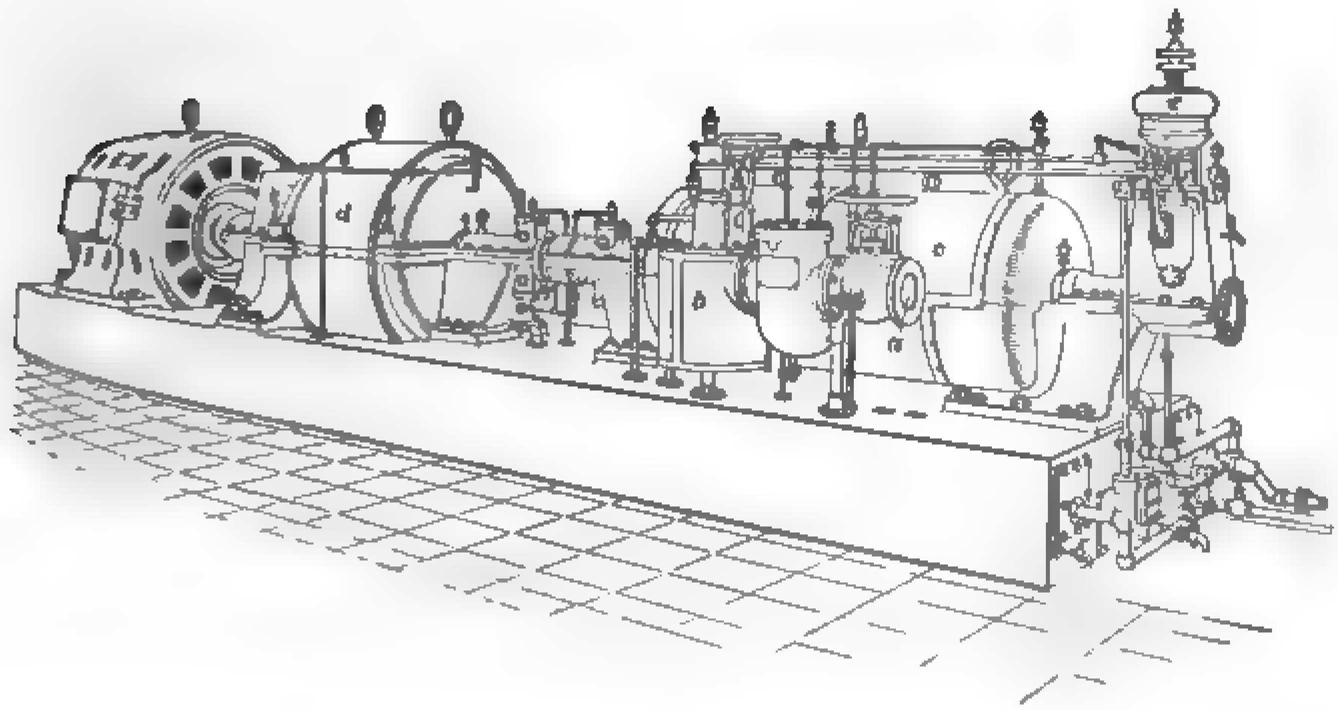

FIG. 13

driven by the turbine; the governor is located at *e*. A turbine of this size runs at a speed of about 1,500 revolutions per minute; one of 400 kilowatts capacity runs at about 3,500 revolutions per minute. Fig. 14, curve *a a*, shows the pounds of steam (water) used per electrical horsepower-hour by a Parsons turbine. At full load of 300 kilowatts the consumption is about 16.5 pounds. Line *b b* shows the total steam consumption per hour.

**34. Curtis Turbo-Alternator.**—Fig. 15 is a perspective view of a 500-kilowatt Curtis turbine set consisting of a turbine direct-connected to a three-phase revolving-field

alternator designed for a speed of 1,800 revolutions per minute. Fig. 16 is a sectional view of the same set showing the arrangement of the various parts. The shaft is vertical, the alternator *A* being mounted on top of the turbine *B*, and the turbine is in two stages—an upper *a* and a lower *b*. Each stage contains three steel turbine wheels *c* with buckets, or vanes, *d* cut on their peripheries. The stationary vanes *e* between the wheels are supported by the turbine casing. Steam enters at *f* and passes through the nozzles

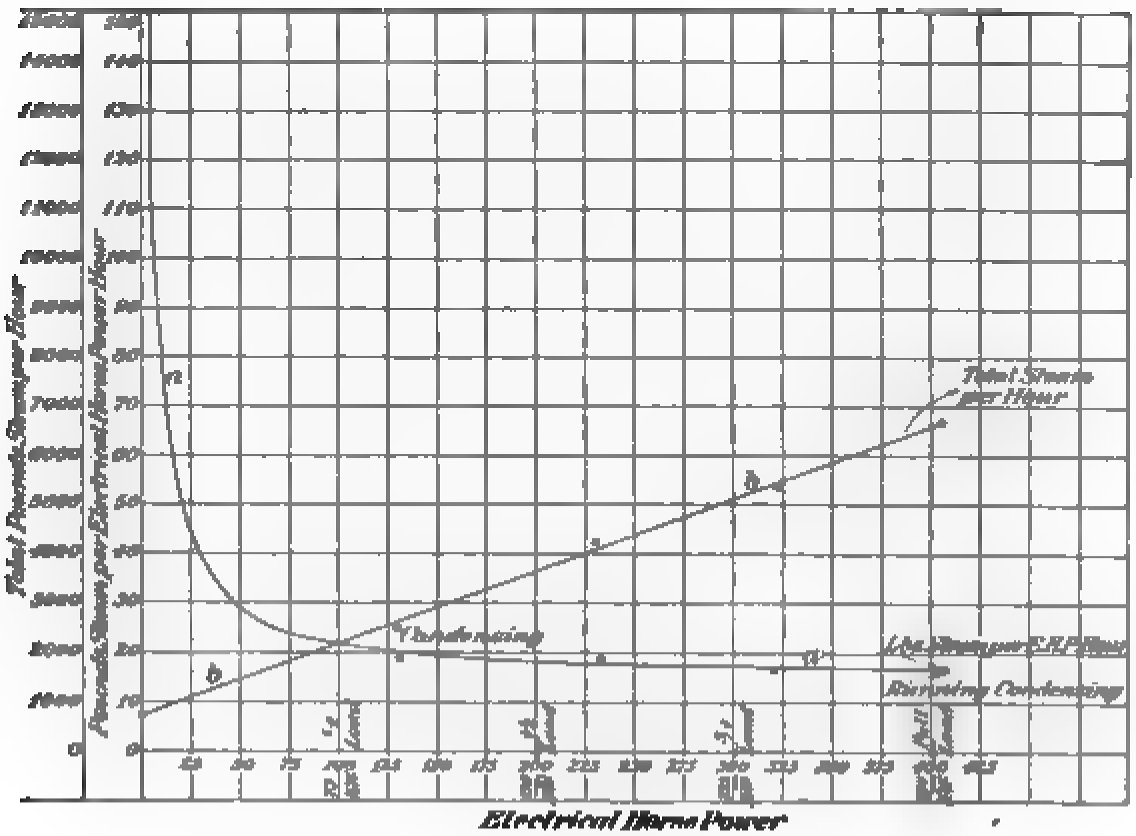


FIG. 14

at *g*, thus impinging on the first wheel. The flow is then reversed by the first set of stationary blades, the steam strikes the second wheel, and so on until it passes through the three wheels of the first stage. It then passes into the wheels of the second stage through openings at *h*, and finally passes, through *k*, into the condenser. In case a condenser is not used, the steam is exhausted through the exhaust connection *l*, the first stage only being used.

In order to obtain a high economy, it is necessary to operate turbines with a high vacuum, hence they are not

operated non-condensing if it is possible to avoid it. In the later types, a surface condenser is placed in the base of the

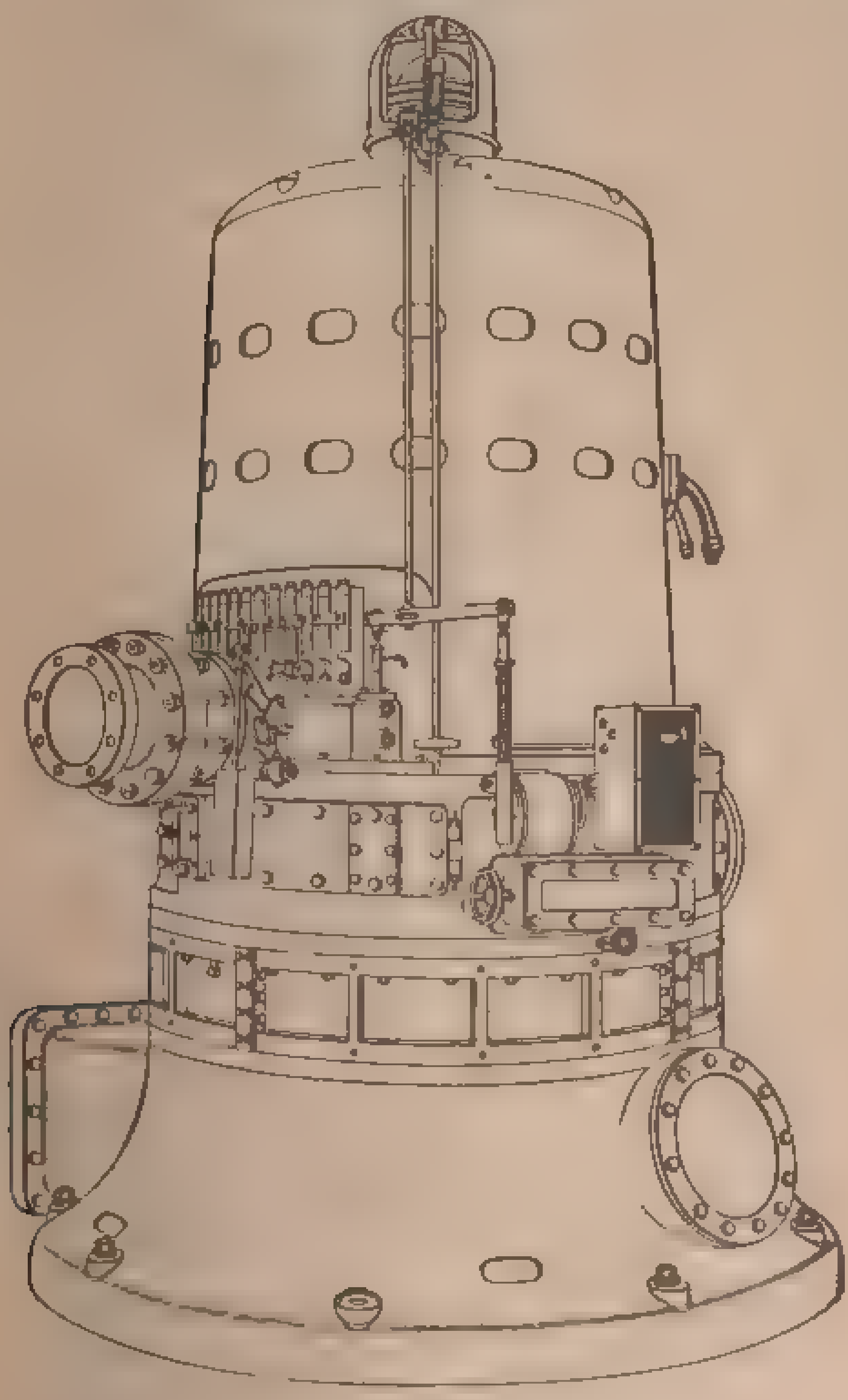

FIG. 15

turbine instead of being a separate device. By this arrangement the liability to leaks between turbine and condenser is reduced and a high vacuum secured, provided a plentiful

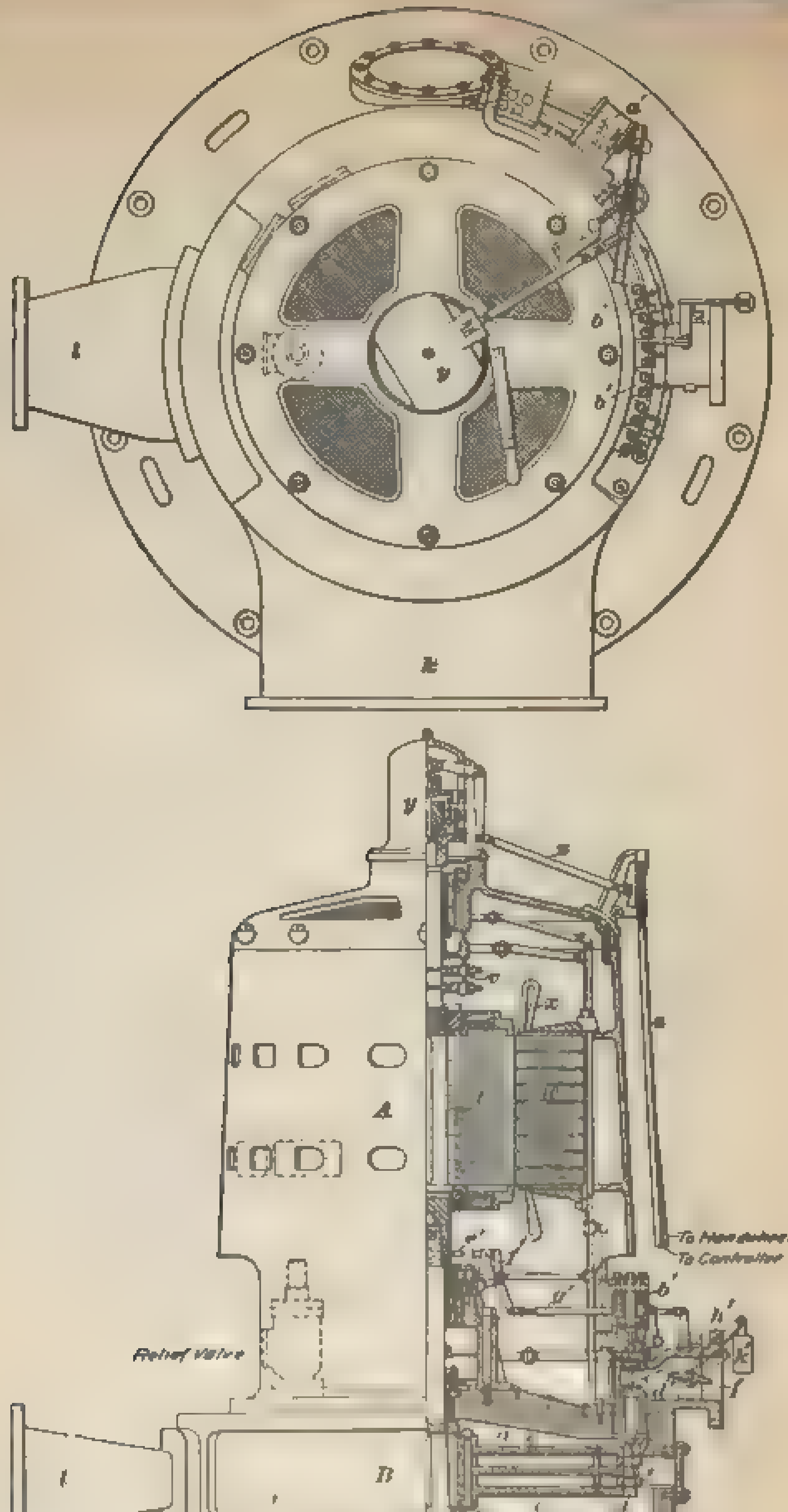


Fig. 16

supply of condensing water is available and a brisk circulation maintained through the condenser.

In Fig. 16 the turbine shaft *m* is supported on a thrust bearing *o* and oil is forced in under the shaft through pipe *p*. The oil flows up and out through the bearing and returns through pipe *r*. The end of the shaft, therefore, rests on a thin film of oil and the downward pressure on the bearing is taken up by the oil pressure. The alternator shaft is coupled to the turbine shaft at *s* and carries a four-pole revolving field *t*, which is built up of sheet-steel stampings. The magnetizing coils are made of copper strip wound on edge and are supplied with exciting current through the collector rings *v*. The stationary armature is shown at *w*; it is constructed in the usual manner and consists of toothed sheet-steel stampings which, when assembled, provide grooves for holding the armature coils *x*.

The governor *y* is located on top of the machine and consists of centrifugal weights acting against a heavy spring. The movement of the weights operates rods *z*, *z* connected to an electric controller located at *a'*. The controller regulates the flow of current (furnished from the exciter, which is driven independently of the turbine set) through a series of small valves operated by electromagnets *b'*. These small pilot valves operate valves *c'* that admit the steam to the several nozzles. Any decrease in speed, caused by an increase in load, causes a corresponding movement of the governor. This moves the controller that operates the electromagnets so as to bring more nozzles into action and thereby supply more power to carry the load. In addition to the regular throttle valve, the turbine is provided with a valve *d'* that closes automatically if, for any reason, the speed should become excessive. A centrifugal device arranged on the shaft at *e'*, flies out when the speed rises above the predetermined amount, thus moving lever *f'*, pulling on rod *g'*, and releasing catch *h'*. This allows weight *k'* to drop and close the valve. Small adjustments in speed, as required, for example, in synchronizing the alternators, can be made by turning the small hand wheel *l'*, thereby

changing the action of the governor slightly. In some of the turbines, particularly in the larger sizes, this adjustment is made by means of a small electric motor controlled from the switchboard.

Fig. 17 shows the steam consumption of a 600-kilowatt Curtis turbine at various loads. The turbine ran at a speed of 1,500 revolutions per minute and was used with a condenser. Steam turbines, like ordinary engines, can be used either

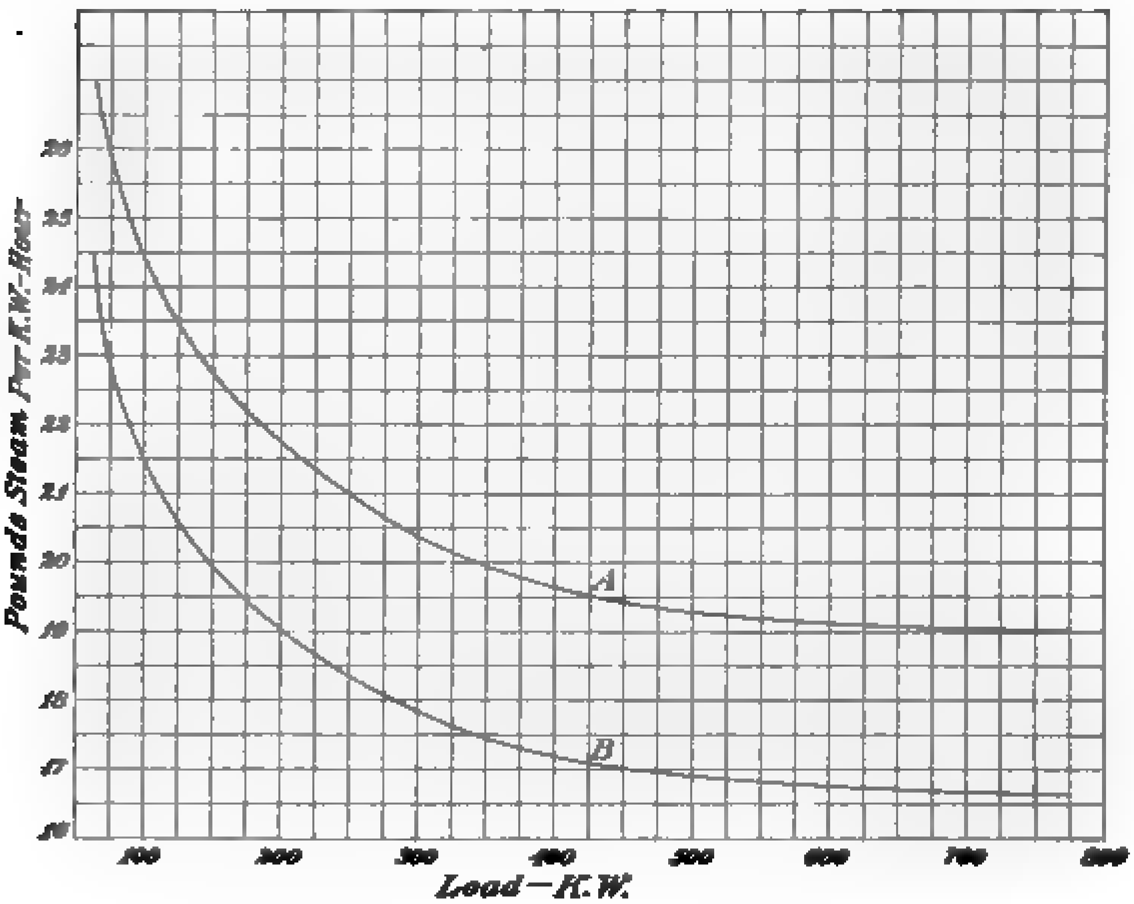


FIG. 17

with or without condensers, but their economy is much better when used with condensers, because if a high vacuum can be maintained it is possible to work with much higher ratios of expansion than are practicable with ordinary engines. In Fig. 17, curve *A*, it will be noted that the steam consumption at full load (600 kilowatts) is about 19.6 pounds per kilowatt-hour. This is equivalent to about 14.6 pounds of steam per horsepower-hour. This, however, is the steam consumption measured at the terminals of the

generator. If the efficiency of the generator is assumed to be 95 per cent. and the mechanical efficiency of the turbine 95 per cent. also, the steam consumption per horsepower, which would be comparable with that per indicated horsepower of an ordinary engine, would be about 13.2 pounds of steam per indicated horsepower-hour. This is much better than would ordinarily be obtained with a reciprocating engine of this size. The steam consumption of the turbine can be considerably reduced by using superheated steam, as shown by the lower curve *B*. This curve was calculated on the assumption that the steam was superheated 150°. The use of superheated steam in turbines is not attended by the difficulties of lubrication that are met with in reciprocating engines.

**35. Advantages of Steam Turbines.**—The important advantages that the steam turbine has over the reciprocating engine may be summed up, briefly, as follows: (*a*) The ability to use highly superheated steam, resulting in greater economy; (*b*) reduced cost per kilowatt capacity of the generating unit, because of increased speed and less weight per kilowatt; (*c*) reduced floor space, resulting in less cost for land and power-station building; (*d*) reduced cost of lubrication, as no cylinder oil is required and less oil is needed for bearings; (*e*) saving in labor, as engine oilers are not required and one engineer can attend to more output than five engineers on reciprocating engines; (*f*) reduced cylinder condensation, because all parts of the turbine are maintained at practically constant temperature; (*g*) reduced cost of foundations, as the turbine is perfectly balanced and has no reciprocating parts; (*h*) a commercial efficiency higher than the reciprocating engine, because there is much less friction; (*i*) increased steam economy and high economy at light loads. The fact that the turbine gives a good steam economy over a wide range of load, whereas the economical load of a reciprocating engine is quite sharply defined, is an important argument in favor of the turbine, particularly in stations handling a variable load. If it becomes necessary

to operate a turbine unit at a comparatively light load, say one-fourth or one-half load, the increase in steam consumption per horsepower-hour or kilowatt-hour output is not nearly as great as it would be with a reciprocating engine. Also, a turbine unit will work more efficiently on overloads. These points will be seen at once by comparing the steam-consumption curve, Fig. 10, with the curves shown in Figs. 14 and 17. The forces acting on the turbine wheels are continuous, hence a uniform rotary motion is secured without the necessity of heavy flywheels. This feature is of particular advantage when power is to be furnished for the parallel operation of alternators, all the difficulties met with on this account in reciprocating engines being absent.

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## CONDENSERS AND CONDENSING APPLIANCES

**36.** In non-condensing engines (that is, engines that are not supplied with a condenser) the steam is exhausted into the atmosphere, and therefore must have, at least, the pressure of the atmosphere acting against it; in practice, the back pressure of steam in a non-condensing engine is scarcely ever less than 16 pounds above vacuum, and is oftener 17 pounds or more. In good condensing engines the back pressure is often as low as 2 pounds above vacuum.

**37.** If a cubic inch of water is converted into steam at atmospheric pressure, it will occupy 1,646 cubic inches of space, and, conversely, if 1,646 cubic inches of steam at atmospheric pressure is condensed into water, it will occupy but 1 cubic inch of space; hence, if a closed vessel is filled with steam at the atmospheric pressure and that steam is condensed to a cubic inch of water, $\frac{1645}{1646}$ of the space will be, theoretically, devoid of air and a perfect vacuum would be the result. This is not strictly true in practice, because the feedwater of the boilers always contains a small quantity of air, which passes into the condenser with the exhaust steam and is released there when the steam is condensed; more or

less air also finds its way into the condenser through leaks around the piston rod and valve stems, and in the case of the jet and the induction condensers, the air contained in the condensing water is also released in the condenser under the influence of the partial vacuum. Moreover, water in a vacuum emits a certain amount of vapor, and if the condenser were successively filled with steam and the steam condensed at each filling, air and vapor would, unless they were removed, accumulate from these various sources until the vacuum was entirely destroyed.

**38.** The object of the **condenser** is to remove a large part of the back pressure on the exhaust side of the piston. By making the engine exhaust into a condenser, the back pressure will be lowered to the pressure existing in the condenser, and consequently, with the pressure on the steam side of the piston remaining the same as before, the net pressure on the piston will be increased by the use of a condenser.

To get rid of the air and vapor that would otherwise accumulate, the condenser is fitted with an **air pump,** or is provided with other means by which the air and vapor are removed from the condenser along with the condensed steam and condensing water. Sometimes a pump is so arranged that it removes air and vapor only and does not pump out the water and condensed steam; a pump of this kind is usually referred to as a *dry-air pump.*

In electric power stations, condensers are used wherever possible because of the reduction in the pounds of steam required per horsepower-hour and a corresponding reduction in the amount of fuel from what would be required by an engine operating without a condenser.

**39. Economy of Condensers.**—The advantages and economies pertaining to the use of condensers may be enumerated as follows:

1. The increase in power gained by reason of the vacuum on the exhaust side of the piston, which, for 26 inches of mercury, is approximately equivalent to a net gain of 12 pounds **mean effective** pressure per square inch of piston area.

2. A reduction in fuel is obtained in ratio to the gain in mean effective pressure and a smaller amount of steam is required; or more power may be obtained with the same fuel consumption.

3. There may also be secured a saving in the cost of boiler feedwater, when the water from the condenser discharge is used over and over again, provided effective methods are applied to extract the cylinder oil. When the condensed steam is used, over and over, for boiler feed, the scaling impurities will, of course, have been completely removed.

4. Because the condensing engine requires less steam per horsepower, it becomes possible to use less boiler-heating surface for a given horsepower of engine.

5. With condensation, in combination with other economic appliances, it becomes possible to obtain the highest economic results of modern practice by using compound engines.

Extra attendance, if any, will be required with a large plant, but not with a small one, when condensers are used.

**40. Comparative Economies.**—The important point to be considered as influencing the use of the condensers is the greater economy that will be shown in power produced from compound condensing engines as compared with a station operated with ordinary high-speed, non-condensing engines. In actual practice, the ordinary high-speed engine frequently uses 35 to 40 pounds of steam per hour per indicated horsepower, and the medium high-speed or simple Corliss engines seldom reach as low as 25 pounds in constant daily service. Therefore, the estimated saving as between the most uneconomical (a station with high-speed engines) and the most economical (a station with compound condensing engines) is from $12\frac{1}{2}$ to 20 pounds of steam per indicated horsepower-hour, according to the capacity and environment of the station.

It must not be forgotten that the steam used by the engine only, is different in quantity from the steam per horsepower used for operating the entire station, and the engine should

not be charged with the steam it does not use. In this connection, especial attention should be given to selecting economical auxiliary appliances for the station. The higher the cost of fuel and water, the greater will be the inducement to use condensing engines and appliances; but when the whole cost of fuel is as low as $1 to $1.50 per ton, the calculations must be made with exceeding care, as it is possible that the interest on investment for condenser equipment, cost of pumping, maintenance, and attendance will nearly equal the value of fuel and water saved. The real gain by the use of condensers will vary according to the type of engines used, and can be estimated by comparing the pounds of steam per hour required to produce a horsepower with and without condensation.

**41.** Table III shows the pounds of steam required by engines used in power stations under actual conditions. This table was originally prepared by the late Charles E. Emery, Ph. D., and has been modified according to some recent tests.

### TABLE III

STEAM CONSUMPTION OF VARIOUS TYPES OF ENGINES

| Type of Engine Name | Steam per Indicated Horsepower-Hour | | | | Per Cent. Gained by Condensing |
|---|---|---|---|---|---|
| | Non-Condensing | | Condensing | | |
| | Probable Limits Pounds | Assumed for Comparison Pounds | Probable Limits Pounds | Assumed for Comparison Pounds | |
| Simple high-speed . . . | 40 to 26 | 33 | 25 to 19 | 22 | 33 |
| Simple low-speed . . . | 32 to 24 | 29 | 24 to 18 | 20 | 31 |
| Compound high-speed . | 30 to 22 | 26 | 24 to 16 | 20 | 23 |
| Compound low-speed . | 25 to 18 | 25 | 20 to 12¾ | 18 | 25 |
| Triple low-speed . . . | 24 to 17 | 20 | 18 to 12¾ | 15 | 20 |
| Triple high-speed . . . | 27 to 21 | 24 | 23 to 14 | 17 | 29 |

### TYPES OF CONDENSERS

**42.** Condensers may be considered under two types, or classes, for power-station service, and the kind of water, its abundance, cost, levels for pumping, cost of fuel, etc., will determine the type to be used in any given case. These types are those that discharge the two waters separately, and those that unite the cooling water with the water of condensation.

#### THE SURFACE CONDENSER

**43.** The **surface condenser** belongs to the class in which the condensing water and the water resulting from the condensed steam are discharged separately. It consists of a large number of small tubes secured at each end into headers and so arranged with connecting chambers that the cooling water passes through the tubes that are surrounded by the exhaust steam.

Fig. 18 shows a section of a Wheeler surface condenser, which will serve to illustrate the principle of surface condensers in general. The exhaust steam from the engine enters at *a* and passes between the tubes *c d e*, where it is condensed. The air pump that clears the condenser of the water of condensation and maintains the vacuum is attached to the outlet *b*. The cold condensing water enters at *f* and after passing through the nests of tubes *d*, *e* passes out at *g*. The exhaust steam on entering at *a* first passes between the group of tubes *c* through which the boiler feedwater is pumped and thus heated before passing into the boiler. This form of condenser therefore contains the features of a feedwater heater and condenser combined.

**44. Cooling Surface.**—In a surface condenser the cooling surface of the tubes should not be less than 1 square foot of surface (measured on the outside of the tubes and between the tube heads) to each 10 pounds of exhaust steam to be condensed per hour. The tubes used vary in diameter from $\frac{5}{8}$ inch to 1 inch and the thickness from No. 16 to

No. 18 B. W. G.; a common size is $\frac{5}{8}$ inch, outside diameter, spaced $\frac{13}{16}$ inch between centers. They should not exceed 12 feet in length, and should be tested under hydraulic pressure to 300 pounds per square inch. When they exceed 6 feet between heads, a central support is desirable. The tubes in the latest condensers are made of an alloy of copper 70 per cent., zinc 29 per cent., tin 1 per cent., though copper tubes have been largely used also; they should be carefully tinned inside and out. Provision must be made for the free expansion and contraction of the tubes under change of temperature, and Fig. 19 shows a method used in the Wheeler condenser for accomplishing this. One end *a* of each tube is flanged and rigidly held in the tube by means of a screw follower *b*; the other end of the tube passes through an adjustable gland *c* that permits free movement of the tube during expansion and contraction. The gland *c* screws up against the packing *d*, thus forming a stuffingbox that permits an end movement of the tube

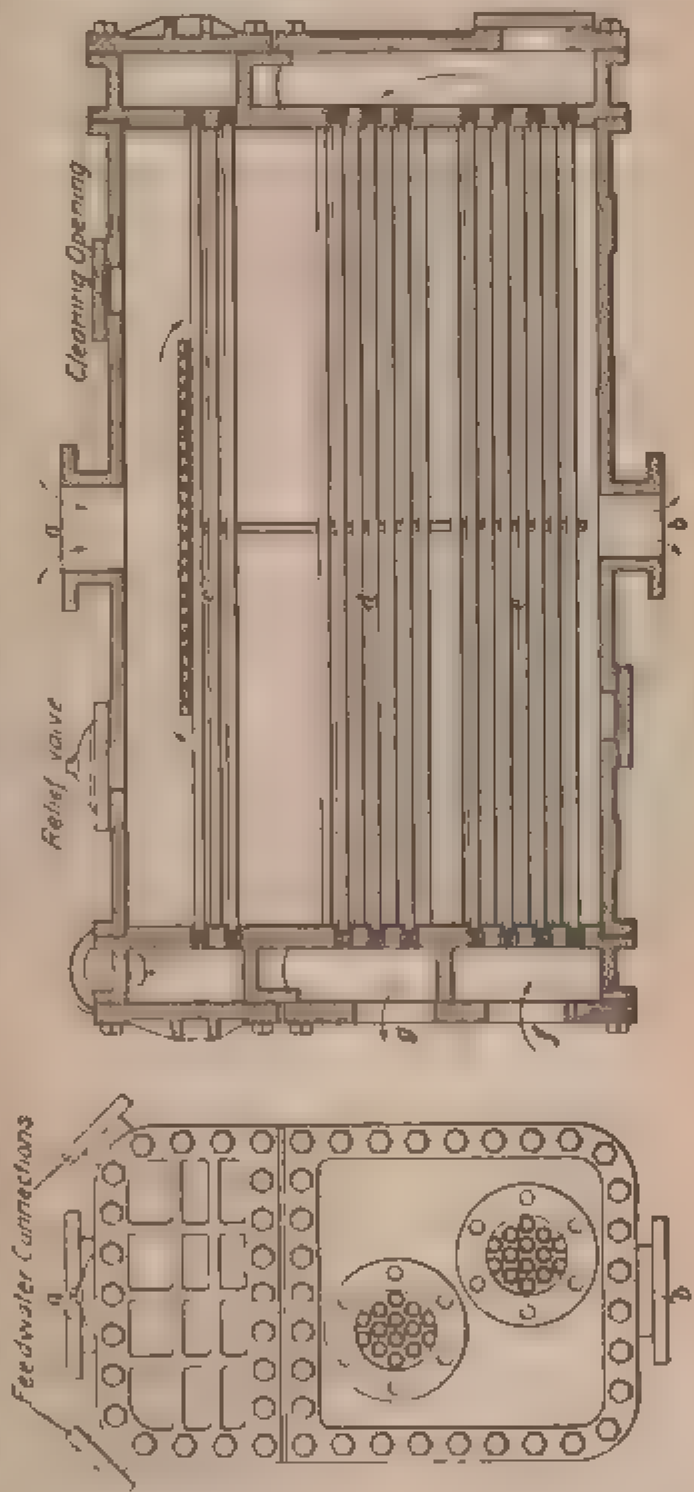


FIG. 18

without allowing leakage. This method of securing rigidly one end of the tube reduces the number of glands or stuffingboxes just one-half. The glands can be readily removed and the packing replaced if it becomes leaky from long use. The circulating water may flow through the tubes at a speed of from 400 to 700 feet per minute.

**45. Air and Circulating Pumps.**—To operate the surface condenser, an **air pump** to withdraw the water resulting from the condensed steam, together with the air contained in the water when it was fed to the boilers, and a **circulating pump** to move the water for cooling the condenser are required. These pumps are usually combined on one frame and bedplate. Fig. 20 shows a common

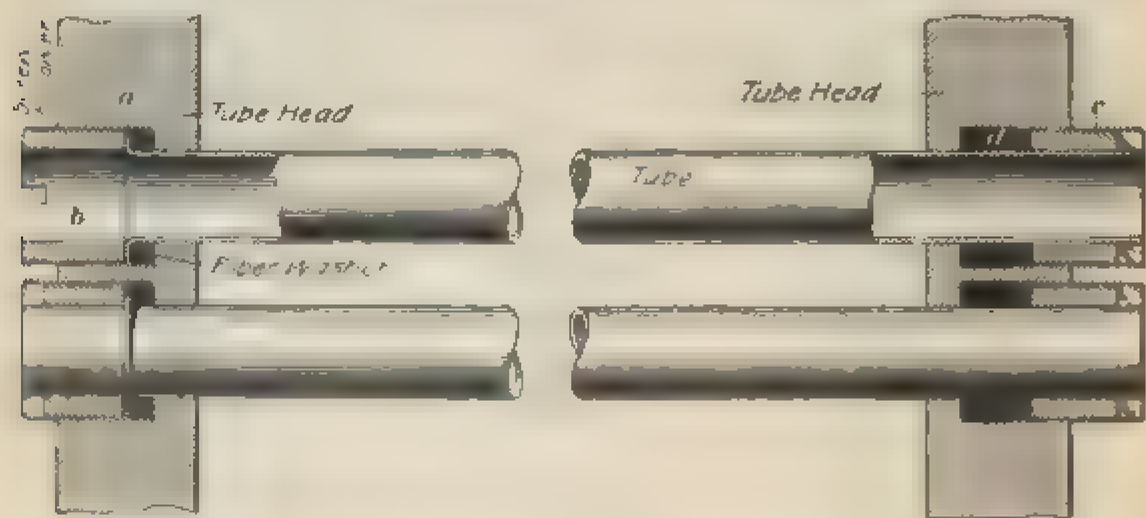


FIG. 19

arrangement of Wheeler surface condenser with air and circulating pumps. The circulating pump is at the right, the air pump at the left, and the steam cylinder for operating the pumps is located between them. The injection water is drawn in at *M* and passes out at *D*. The exhaust steam enters at *A* and after being condensed is discharged, by the air pump, from *K* to be used again in the boilers.

**46. Advantages and Disadvantages of Surface Condensers.**—An objection frequently urged against using surface condensers is that grease from the cylinder oil carried over by the exhaust steam accumulates on the steam side of the tubes and reduces the efficiency of the cooling surface;

but this may be prevented by an efficient grease extractor. The surface condenser for a given capacity is the highest in first cost; but where boiler feedwater is an important item of operating expense, the surface condenser will save most of it in the form of distilled water, and this saving in the water will more than equal a large interest on the difference in cost between a surface-condenser and a jet-condenser equipment. Only a trivial amount of water is lost, and fresh water is required to make up such loss; in fact, a little natural water must always be added to the distilled water.

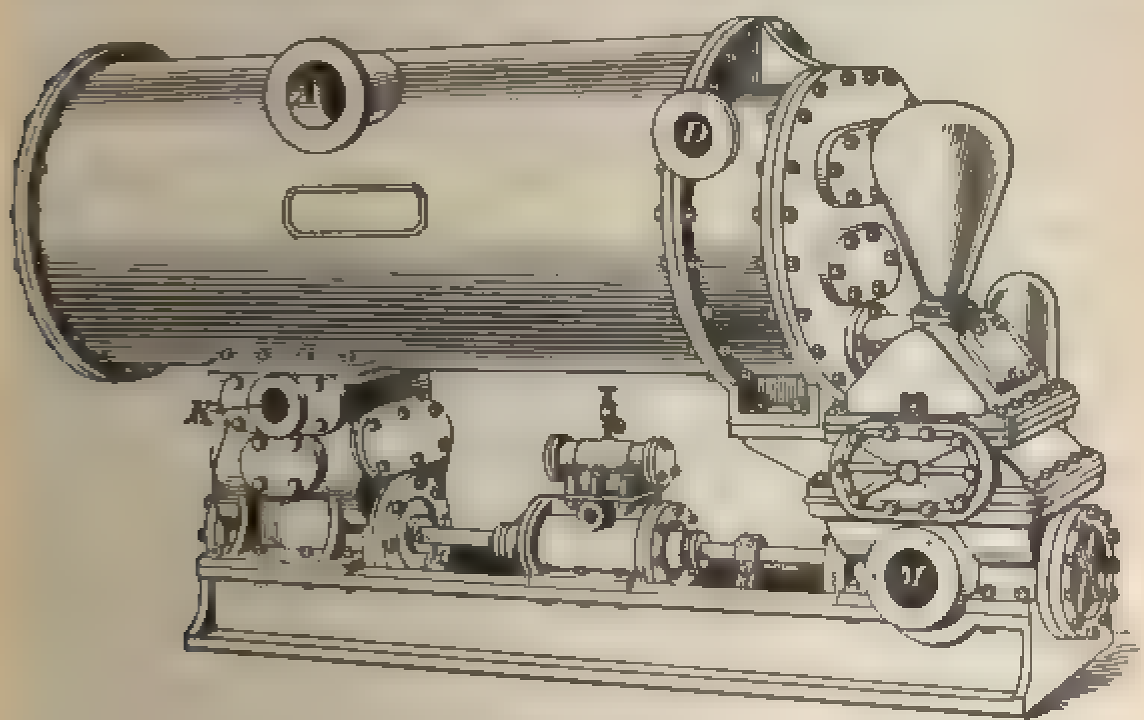


FIG. 20

A valid objection to the use of distilled water in boilers is that it is too pure, it being a well-known fact that pure or distilled water is a solvent of iron. In steam plants using condensing engines, and returning condensed steam only to the boilers, corrosion or pitting is found to take place, unless a portion of undistilled or natural water is mixed with the returns from the condensers.

When testing the exact amount of steam used by an engine, the surface condenser is a satisfactory adjunct, as the water independently discharged by the air pump can be weighed, and if carefully handled, should show the weight of steam used by the engine in performing its work.

**47. Operation of Surface Condensers.**—Surface condensers require compliance with the following conditions in their care and operation if the best results would be obtained:

To insure good results, it is absolutely necessary to place the air pump below the condenser. In connecting two or more engines to one condenser, with a common steam inlet, use double elbows of large radius, and avoid straight tee connections, otherwise one engine is liable to exhaust against the other.

All suction pipes should be provided with a suitable strainer having openings at least $1\frac{1}{2}$ times the area of the pipe. Wrought iron should not be used for salt water; copper or cast iron will be more satisfactory.

Before starting the main engine, the air and circulating pumps, if independent, should be started with the air pipe on the condenser open to expel the air from the tubes and air chambers. If the condenser is hot, sufficient water should be circulated to cool it, and the engine then started slowly. The automatic open-air exhaust relief valve is closed by automatic pressure, and should be examined daily to see if it is properly seated and lifts freely. It is important to remember that a high vacuum requires a tight engine and tight connections. Any vibration of the pointer on the vacuum gauge indicates air leaks. To test the tightness of a condenser, the air-pump connections must be blanked off, and the condenser filled with water, and the water bonnets on the chambers removed. If any tubes that cannot be immediately replaced are found leaking, a pine plug driven in each end of the tube will answer temporarily. If it is necessary to remove a tube that is packed around the end, it should be closed at the expansion end with a proper tool before attempting to pull the tube out.

To avoid cylinder oil in dilution with the condensed water, a vacuum-tight oil separator will be found most efficient, and should be connected between the engine exhaust and the condenser; if this is not done and it is intended to use the condensed water for boiler-feed purposes, it should be purified after leaving the condenser, which will be a more or less

troublesome method. To keep the condenser clean, where engines are in constant service, a gallon of kerosene oil or a solution of sal-soda can be occasionally injected with the exhaust steam. Surface condensers should be cleaned once a week.

### THE JET CONDENSER

**48.** In the **jet condenser,** which represents the second class of condensers, the exhaust steam from the engine enters at the top of the condenser chamber, and is condensed in an effective manner by meeting at once the spray of injection water. Three classes may be considered—the *air-pump and jet condenser*, the *barometric-column condenser*, and the *induction condenser*.

The valuable features of the jet condenser are that it occupies but little floor space, does not require a costly foundation, can usually be connected close to the engine, and, being independent, can be started in advance of the engine, thus obtaining a vacuum as soon as the engine is in operation. The quantity of cooling water can be varied to meet the demands of the engine according to its load.

**49. Examples of Air-Pump and Jet Condensers.** The combined outfit of **air-pump and jet condenser** is usually of the horizontal type, all parts being designed for a compact setting on a continuous bedplate. Fig. 21 is a view of a Blake jet condenser. *A* is the condenser, *B* the air pump, and *C* the steam cylinder for driving the pump, which, in this case, is of the direct-acting type.

Fig. 22 shows a section of a Worthington independent jet condenser. The cold water enters the condenser at *b*, passes down the spray pipe *c*, and is broken into a fine spray by the cone *d*. The exhaust steam in the meantime comes in at *a*, and, mingling with the spray of cold water, is rapidly condensed. The velocity of the entering steam is imparted to the water, and the whole mixture of steam, water, uncondensed vapor, and air is carried with a high velocity through the cone *f* into the air pump cylinder *g*, whence it is forced by the pump through the discharge pipe *j*.

**50.** This condensing apparatus is operated as follows: The air-pump having been started, a vacuum is formed in the condenser, the exhaust pipe, the engine cylinder, and injection pipe; this causes the injection water to enter through

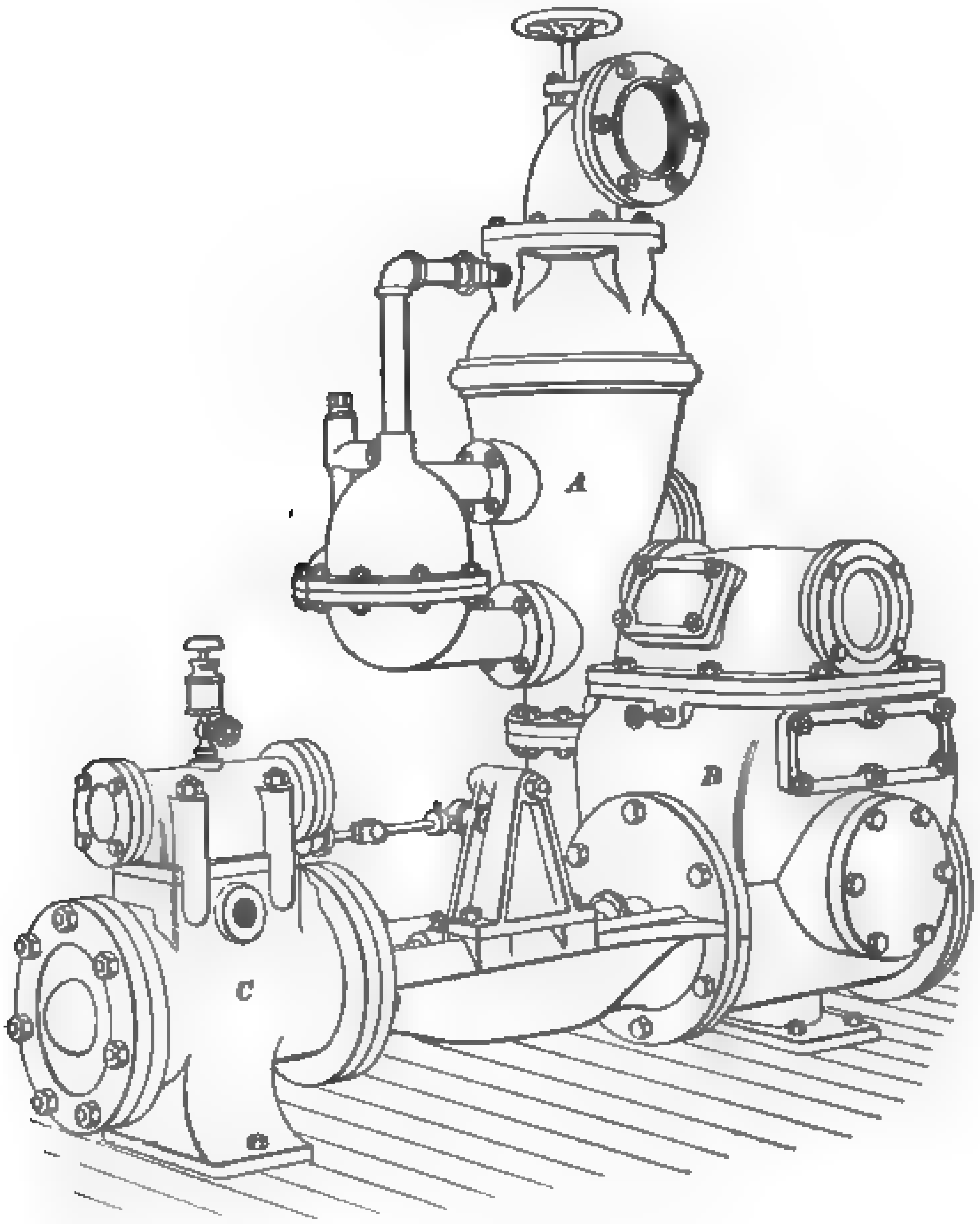


Fig. 21

the injection pipe attached at *b* and to flow through the spray pipe *c* into the condenser cone *f*. The main engine being then started, the exhaust steam enters through the exhaust pipe attached at *a*, and, coming into contact with the cold

water, is condensed. The spray pipe $c$ has at its lower end a number of vertical slits through which the injection water passes and becomes spread out in thin sheets. The spray cone $d$, by means of its serrated surface, breaks the water passing over it into fine spray and thus insures a rapid and

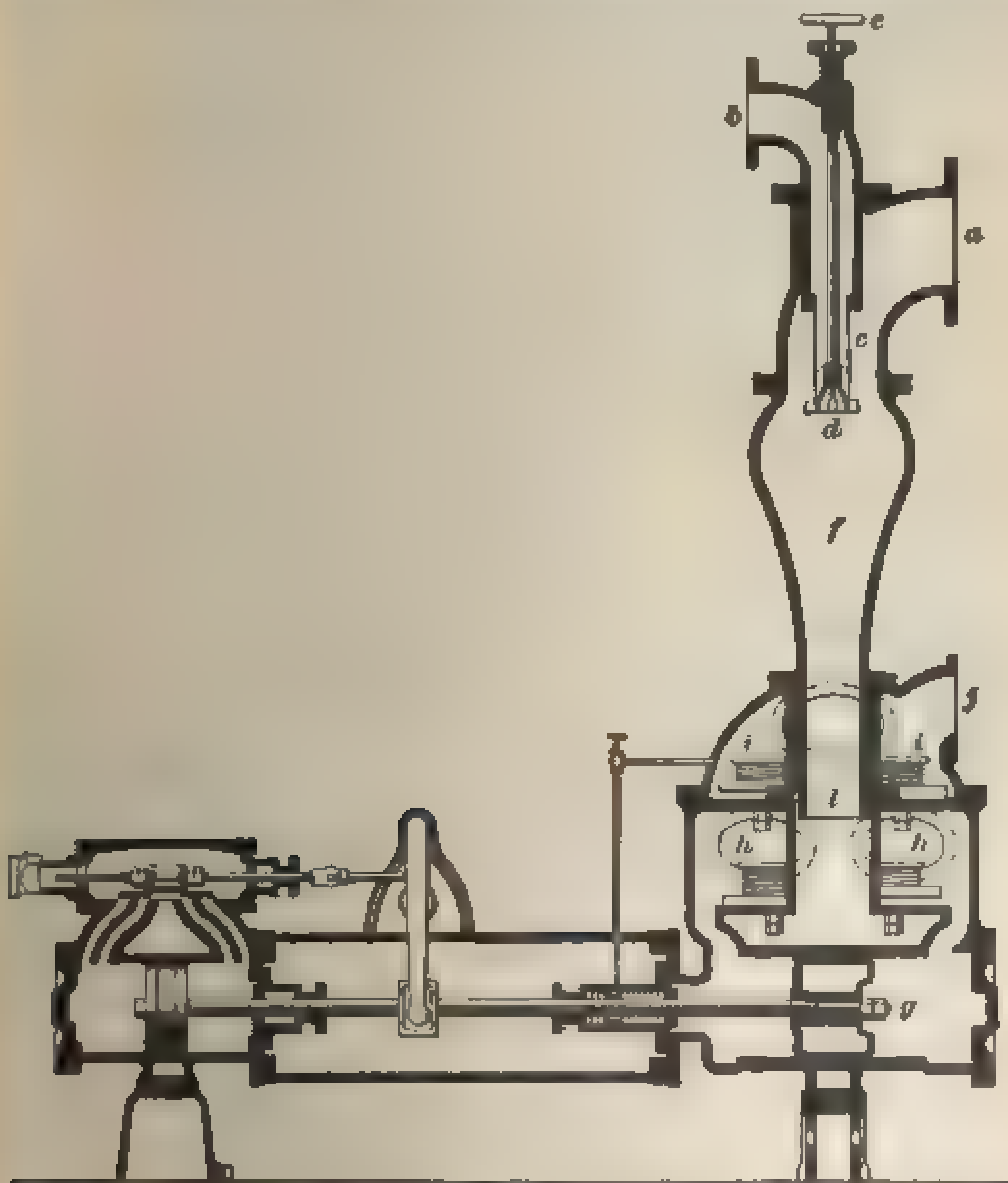


FIG. 22

thorough admixture with the steam. This spray cone is adjustable by means of a stem passing through a stuffingbox at the top of the condenser and is operated by the handle $e$.

**51.** In Fig. 23 is shown a jet condenser in connection with the boiler and engine. The exhaust pipe $A$ leads directly to the condenser; the injection pipe $B$ draws water

from the reservoir *C*. After the steam is condensed, the mixture of exhaust steam and injection water is discharged through *D* into the sewer. A portion of this discharge, however, flows through *E* to the feed-pump *G*, which forces it through the coil in the heater *F* to the pipe *H* leading to the boiler. The exhaust from the two pumps is discharged into the feedwater heater through the pipe *M*. It will be noticed that water from the overflow pipe *D* enters the feed-pump under a slight head. This is because the water is heated by

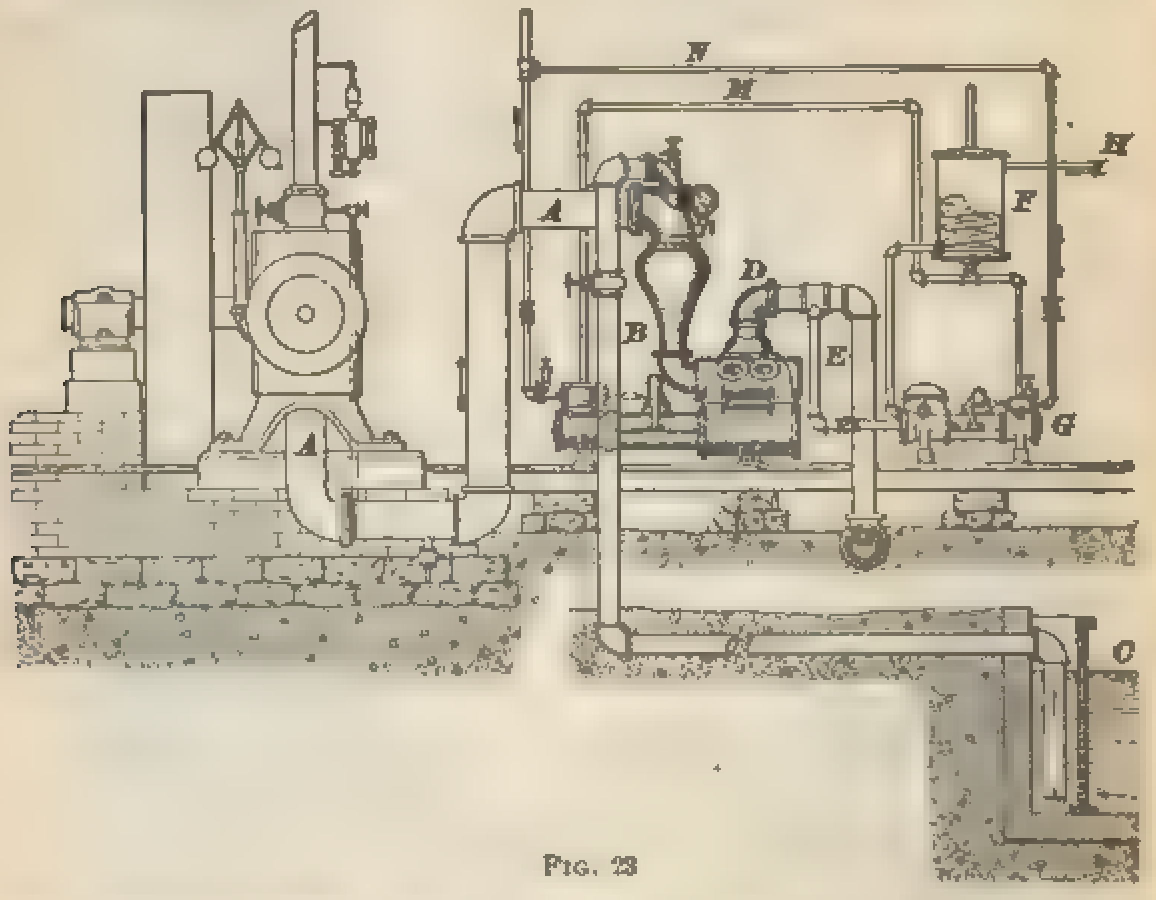


Fig. 23

the exhaust steam, and hot water cannot be raised by a pump like cold water. A pipe *N* leads from the boiler and supplies steam for both pumps.

**52.** The air pumps shown in Figs. 21 and 22 are driven by single-cylinder, direct-acting engines. With a single steam cylinder, the steam follows nearly the full length of the stroke and thus materially reduces the economy sought for with a condenser. The compound steam cylinder is an improvement on the single-cylinder type, and will more than save, in steam, the extra cost. Fig. 24 shows a large,

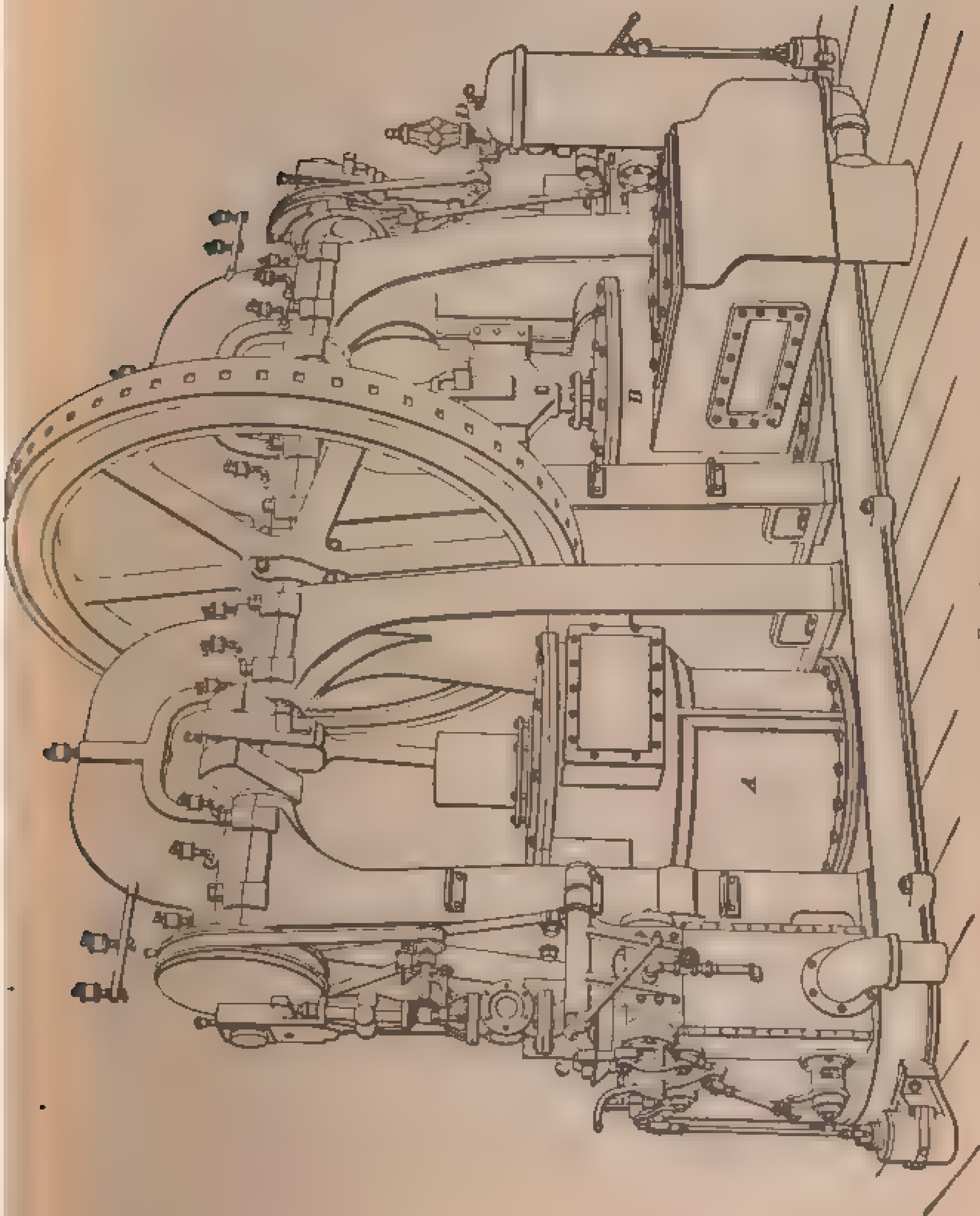


FIG. 24

Conover, combined air and circulating pump used in very large stations where a condenser of the highest economy is desired. The air pump *A* is of the single-acting type and the circulating pump *B* is double-acting. The driving engines *C*, *D*, situated at either end, are of the vertical compound type fitted with Corliss valve gear. This type of outfit, provided with compound steam cylinders and flywheel, possesses many advantages in the way of uniform speed and economy of steam over the direct-acting type; hence, it is suitable for large units where the extra expense is warranted.

**53. Barometric Column, or Siphon, Condenser.** This differs from the common jet condenser in that no air pump is required to remove the air, uncondensed vapor, and water, but a circulating pump or head of water is needed to supply the injection water when the lift is more than 20 feet. The vacuum is generated and maintained by a column of water flowing downwards through a vertical pipe of not less than 34 feet in length, having its lower end immersed in the water of the hotwell.

**54.** It will be remembered that a column of water 34 feet in height will just balance the atmosphere at the sea level when the barometer stands at 30 inches, but if an additional amount of water be allowed to enter the upper end of the water pipe, the equilibrium between the column of water and the column of air outside will be disturbed, and an amount of water corresponding to that allowed to enter at the upper end of the pipe or tube will flow out at the lower end.

This is the principle of the siphon condenser. So long as the proper amount of water continues to flow into the upper end of the pipe and a corresponding amount flows out at the lower end, the air and vapor in the condenser will be carried out by the descending water and a vacuum will be formed and maintained. If the area of the pipe is contracted into a neck, or throat, the velocity of the falling water will be accelerated and the action of the condenser will be improved thereby.

It is important that the stream of injection water entering the condenser should have a steady and continuous flow, and there must be no air leaks in the exhaust pipe or condenser. The siphon condenser is often, but wrongly, called the *injector condenser.*

**55.** An illustration and a description of an example of this type of condenser, known as the *Baragwanath condenser*, is here given.

Fig. 25 represents a sectional view, in which *a* is the exhaust pipe; *b* the injection pipe; *d* the long discharge pipe, or *tail-pipe;* and *e* the hotwell. The steam enters through exhaust pipe *a* and flows through the exhaust nozzle *f* into condensing chamber *g*. Here it is met and condensed by the injection water that enters from the water-jacket *h* into the condenser in a thin conical sheet, flowing through the annular opening between the exhaust nozzle *f* and the prolongation of the shell of the condenser forming the inverted cone *i*. A vacuum is formed in the condensing chamber *g* by the condensation of the steam and by the air and uncondensed vapor being entrapped and carried out of the chamber by the cylindrical stream of water. The injection water and water of condensation flow from condensing

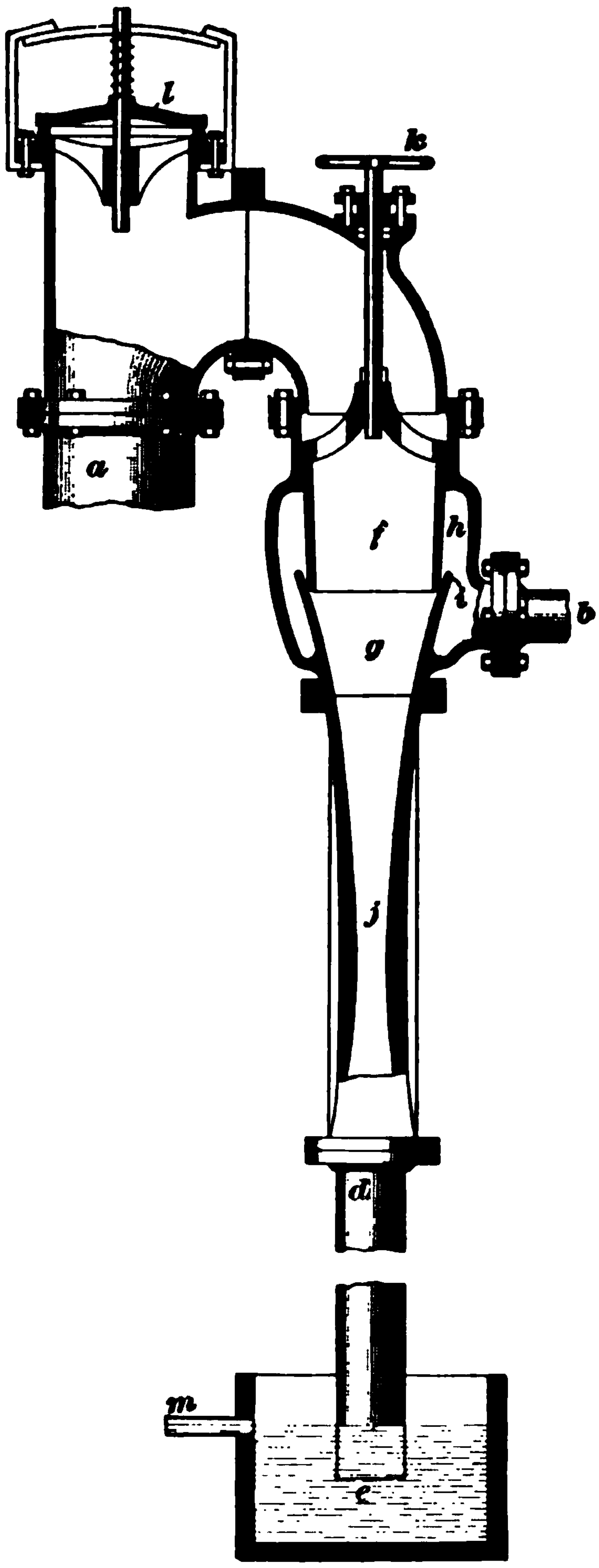

FIG. 25

chamber *g* through the throat *j* with such velocity as to carry with them the air and vapor that pass over with the steam and the injection water.

The exhaust nozzle *f* is adjusted by means of the wheel and screw spindle *k*, and can be set so as to admit just the right quantity of injection water. An automatic atmospheric relief valve *l* is fitted for the purpose of discharging any excessive accumulation of air, steam, or vapor that may collect in the exhaust pipe into the atmosphere. A hotwell overflow, or discharge, pipe *m* is always fitted to the hotwell.

**56.** In the barometric-column form of condenser, the throat of the condenser head is usually elevated at least 34 feet above the water level in the hotwell, so that the descending column of water, combined with the condensed steam, will create and maintain the vacuum. This condenser application combines three features: the exhaust leading into the condenser head at an elevation of about 35 feet above the hotwell; the water supply pipe to furnish the injection water at the condenser head; and the discharge pipe through which is carried off the combination of the condensed steam and the cooling water. This condenser is of low cost, and very economical where the injection water can be obtained from a tank, reservoir, or stream at such an elevation as to render pumping unnecessary, and under such conditions, with a supply pipe of ample size and a continuous flow of water, will show as good economy as can be obtained with a regular surface or jet condenser.

**57.** Where water is not naturally delivered at a convenient elevation, power must be expended to elevate the water to the height of the condenser head to insure proper supply. When considering the application of this type of a condenser, where the water must be pumped to an elevation of 30 feet, it is important that careful calculation be given to the cost of lifting the water. When the water must be pumped to the condenser head it should also be remembered that the descending columns will produce a siphon action,

and will thus partially balance the ascending column, thereby reducing the work on the pump in proportion.

Although the condenser is placed at a height of 34 feet above the hotwell, the vacuum assists the circulating pump

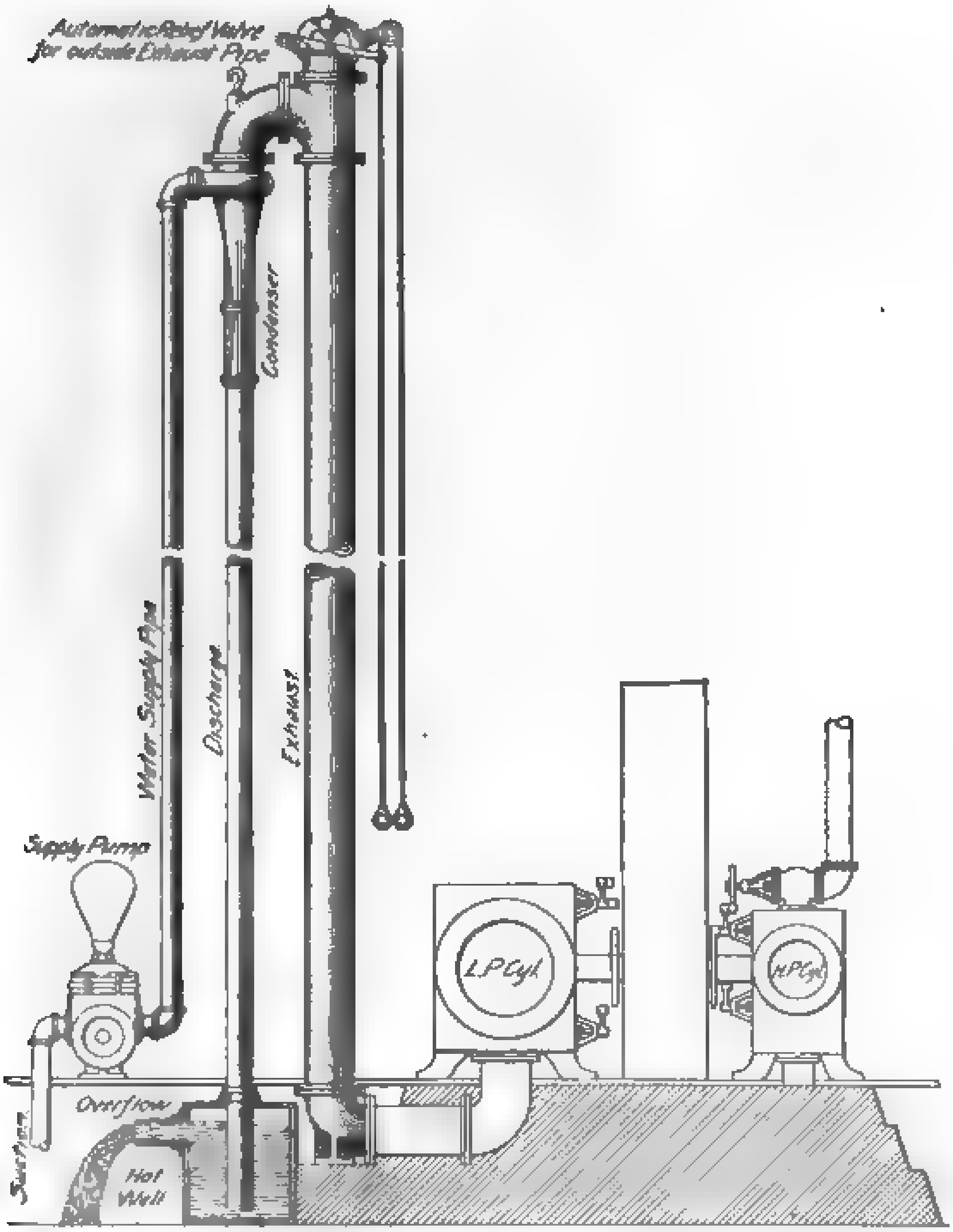


FIG. 26

in a proportionate degree, so that with a vacuum of $24\frac{1}{2}$ inches the actual height that the water is forced by the pump is but 7 feet. Fig. 26 shows the general arrangement of a

Knowles condenser of this type, the condensing water being supplied from a pump. Fig. 27 shows an arrangement of the same condenser where the exhaust steam is first passed through a feedwater heater and where the condensing water is siphoned from a flume or tank instead of being pumped.

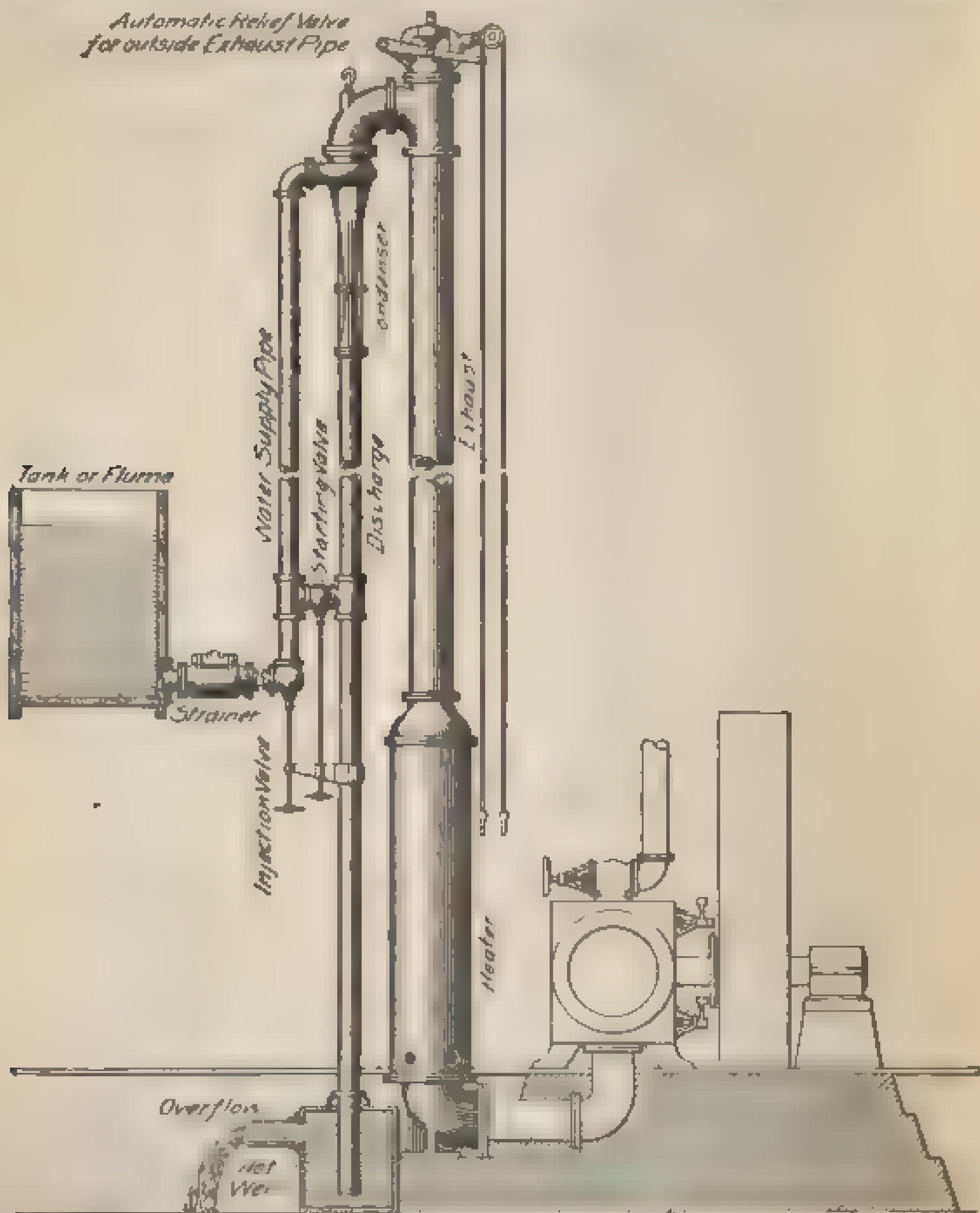


Fig. 27

**58. The Induction Condenser.**—The operation of the **induction condenser** is based on the same principle as that of the steam injector, used so largely for boiler feeding, and

it may properly be called an **injector condenser**, although it is not given this name by the trade.

Fig. 28 represents a partial sectional view of a condensing apparatus of this type; it is known as the *Korting universal exhaust-steam induction condenser*. Referring to the figure, the exhaust steam enters at *a*, and after passing through the balanced horizontal check-valve *b* enters the water chamber *c*; it then passes through the inclined openings in the tube *d* into the condensing chamber *e*, where it is met by the injection water and is condensed, forming a partial vacuum. The condenser is started by a supplementary jet of steam or stream of water. The vacuum in the chamber *e* induces the injection water to be siphoned into the condenser from the supply reservoir *f* through the injection pipe *g* and the strainer *h*, from whence it flows into the annular space *i* around the ram *j*, passing into the condensing chamber *e* through the annular opening *k*, where it meets the exhaust steam, which is then condensed. Here the injection water and the water of condensation intermingle and with the air and vapor are carried down the discharge pipe *l* into the hotwell *m*, the surplus water flowing into the sewer *n*.

**59.** To obtain the best results under the varying quantities of steam it may be called on to handle, this condenser requires that it shall be adjustable. This is accomplished by the ram *j* being made tapering and capable of being raised and lowered at will, which operation varies the size and capacity of the annular opening *k* and controls the volume of water admitted to the condensing chamber *e*. The ram is adjusted by the hand wheel *o* acting through a rack and pinion. The area of opening required by the steam that enters the condenser is regulated by the sleeve *p*, which covers more or less of the openings in the tube *d*, as may be required. This sleeve is raised or lowered by the hand wheel *q*, which also acts through a rack and pinion.

**60.** Like all condensers, this one requires a valve that opens into the atmosphere to relieve it of any accumulation of steam, air, or vapor that may collect in it. This is

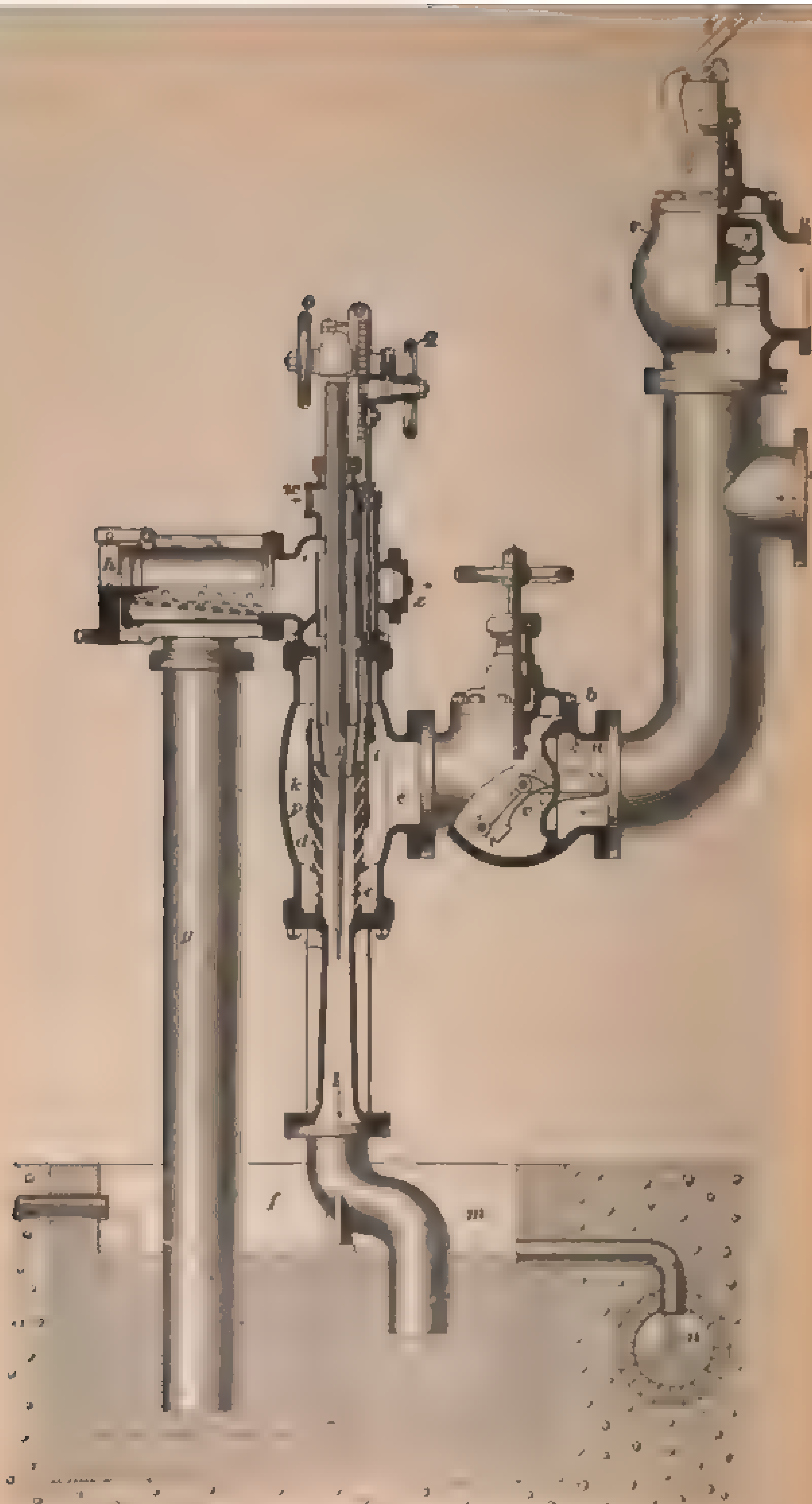

FIG. 2.

provided in the *automatic free exhaust valve r*, which valve closes automatically when there is a vacuum in the condenser and opens when the vacuum is destroyed. It is fitted with a piston *s* to prevent the valve hammering. If it should become necessary or desirable to cut the condensing apparatus out of service and run the engine non-condensing, the free exhaust valve may be locked open by turning the hand lever *t* to the left.

The operation of the check-valve *b* is as follows: The inclined suspension bar *u* has a tendency to open the valve, while the inclined supporting bar *v* has a tendency to close it. Thus, the valve is balanced by its own weight, which is so distributed that there is always a slight excess of closing tendency. The object of this valve is to prevent the water in the condenser being siphoned into the steam cylinder.

**61.** When the injection water is supplied to the condenser under pressure, as from an elevated tank or from the street main, instead of being siphoned up, the openings *w* and *x* are blanked.

When the injection water is siphoned into the condenser and water under pressure is used for starting, the starting water enters at the opening *w* and the opening *x* is blanked.

When the injection water is taken under high suction and steam is used for starting, the steam enters through the opening *w*, a check-valve is attached at the opening *x*, and an overflow pipe is connected with the check-valve to discharge free or into the discharge pipe *l*.

This type of condenser has its limits of operation. If the load on the engine is variable, or the condenser is not of proper proportion, there may be times when the small volume of exhaust steam will be insufficient to impart the necessary velocity to the large amount of water.

The advantages over the ordinary air-pump condenser are: low first cost; absence of moving parts, with consequent certainty of action; small space taken up, thus enabling separate condensers to be applied to each engine, and obviating the use of long exhaust pipes with complicated

[illegible] is practically [illegible] exhaust caused by [illegible] unless a man is [illegible] manipulate the valves as the [illegible]

## [illegible] CONDENSER PRECAUTIONS

[illegible] with a condenser equip- [illegible] also the observ- [illegible] of the work. [illegible] all joints and pipe con- [illegible] perfectly tight [illegible] a vacuum exists within the [illegible] pressure the external air will [illegible] places. It is therefore wise to specify

that the system shall test a certain vacuum at the engine cylinder, and shall remain air-tight for a specified time, retaining this vacuum after the engine and condenser are closed down. Unsuspected air leaks may be discovered by testing over the entire system at every joint with the flame of a lighted candle; if the air is leaking in, the flame of the candle will be drawn in at the defective point. Close all leaks by taking up all bolts and nuts, and coating the joints with asphaltum varnish.

63. **Position of Vacuum Gauge.**—In the application of any type of condenser it is important that the vacuum gauge showing the resulting vacuum obtained by using the condenser, should be connected directly, or as close as possible, to the exhaust pipe of the low-pressure cylinder of the engine, in order that the actual vacuum in the engine cylinder may be determined. If the exhaust pipe is a long one and the vacuum gauge is connected near the condenser, it is quite possible that, because of friction or air leaks in pipes or valves, a difference of 2 or 3 inches better vacuum will show at the condenser than at the low-pressure cylinder, and the true results will not be known. The vacuum gauge should be standardized to absolute accuracy.

64. **Heating Feedwater.**—This can be accomplished by using a closed heater located in the exhaust line near the engine, where the feedwater passing through it will get the benefit of the heat in the exhaust steam before the latter reaches the condenser.

65. **Automatic Relief Valve.**—Each engine should be protected by an automatic exhaust relief valve that will act promptly and allow the engine to exhaust into the atmosphere in case of any fault in the working of the condensing apparatus. Any condenser is liable to lose its vacuum by the failure of the air pump or its attachments, or by the partial or entire stoppage of the supply of cooling water. Under such conditions, if a relief valve is not provided, the exhaust will accumulate pressure and slow-down or stop the engine. Fig. 29 illustrates one type of automatic

exhaust relief valve. In case the back pressure becomes excessive, valve *a* is lifted from its seat and the steam allowed to exhaust into the atmosphere. The dashpot at *b* steadies the movements of the valve.

It is desirable that air pumps and jet condensers be fitted with composition-lined cylinders and composition piston rods, valve seats, valve bolts, springs, etc. The difference between the cost of composition fittings and iron or steel

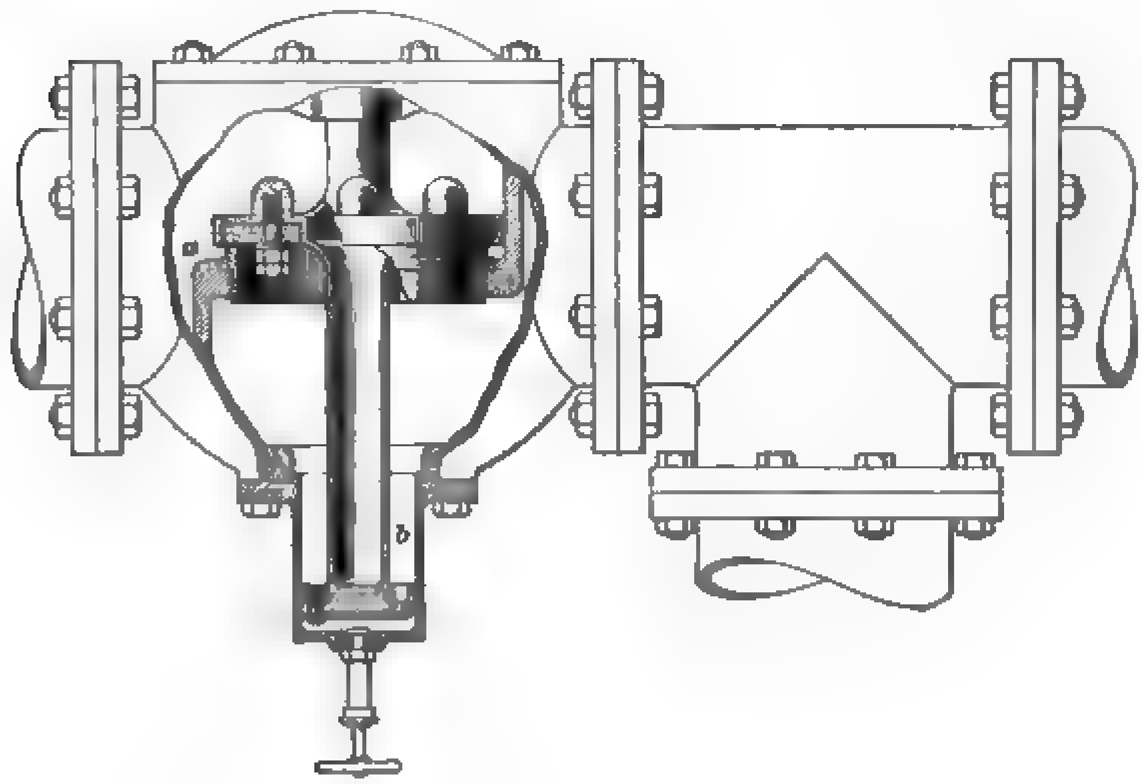


FIG. 29

fittings is more than made up within a short time by the extra cost of repairs and maintenance if an iron-fitted pump is used.

**66. Grease Extractors.**—There are several effective **grease extractors** on the market, and every plant should be fitted with an efficient appliance for this purpose. The saving in cylinder oil and the greater purity of the water from the exhaust for boiler feed will well repay the cost of the grease extractors.

## WATER USED FOR CONDENSING

**67.** When considering the application of any condenser, the character of the injection water (whether fresh, salt, acidulous, or otherwise impure), the maximum temperature, the amount of available supply, and the distance horizontally and vertically that the water has to be raised, must be investigated. Instances have occurred where engineers, overlooking the character of the cooling water, have installed surface condensers to use circulating waters so largely impregnated with sewage or vegetable matters that the heat of the exhaust steam caused the impurities contained in the water to be deposited on the tubes of the surface condensers in a jelly-like formation, thus quickly cutting down the efficiency of the condenser, and ultimately making it necessary to change to another type of condenser.

**68. Determination of Amount of Injection Water.** The amount of water required to condense thoroughly the steam from an engine is dependent on two conditions: the total heat and weight of the steam, which represents the work to be done, and the temperature of the injection water, which represents the value of the cooling agency by which condensation of the steam is to be accomplished. Generally stated, with 26 inches vacuum, and injection water at ordinary temperature (not exceeding 70° F.), from 20 to 30 times the quantity of water evaporated in the boilers (feedwater) will be required for the complete condensation of the exhaust steam from an engine.

The effectiveness of the injection water decreases very rapidly as its temperature increases, and at 80° F. 35 times, and at 90° F. 52 times the feedwater has to be employed; on the other hand, if the temperature be lower, less water is required. The approximate amount of condensing water required per pound of steam condensed can be obtained by the following rule:

**Rule.**—*Subtract the temperature of the air-pump discharge from 1,190 and divide the remainder by the rise in temperature of the condensing water.*

## TABLE IV

### POUNDS OF INJECTION WATER REQUIRED PER POUND OF STEAM CONDENSED

| Temperature of Discharge From Air Pump Degrees F | Entering Temperature of Injection Water in Degrees F. | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 |
| | Pounds of Condensing Water Required per Pound of Steam | | | | | | | | | | | | | |
| 90 | 20.0 | 22.0 | 24.4 | 27.5 | 31.4 | 36.7 | 44.0 | 55.0 | 73.3 | 110.0 | 22.0 | | | |
| 92 | 19.2 | 21.1 | 23.4 | 26.1 | 29.7 | 34.3 | 40.7 | 49.9 | 64.6 | 91.5 | 156.8 | 549.0 | | |
| 94 | 18.6 | 20.3 | 22.4 | 24.9 | 28.1 | 32.2 | 37.8 | 45.7 | 57.7 | 78.1 | 121.8 | 274.0 | | |
| 96 | 17.9 | 19.5 | 21.4 | 23.6 | 26.7 | 30.4 | 35.3 | 42.1 | 52.1 | 68.4 | 99.4 | 182.3 | | |
| 98 | 17.3 | 18.8 | 20.6 | 22.7 | 25.4 | 28.7 | 30.1 | 39.0 | 47.5 | 60.7 | 84.0 | 136.5 | 364.0 | |
| 100 | 16.8 | 18.2 | 19.8 | 21.8 | 24.2 | 27.2 | 31.1 | 36.3 | 43.6 | 54.5 | 72.7 | 109.0 | 218.0 | |
| 102 | 16.2 | 17.5 | 19.1 | 20.9 | 23.1 | 25.9 | 29.4 | 34.0 | 40.3 | 49.5 | 64.0 | 90.7 | 155.4 | 544.0 |
| 104 | 15.7 | 17.0 | 18.4 | 20.1 | 22.2 | 24.7 | 27.8 | 31.9 | 37.4 | 45.2 | 57.2 | 77.6 | 120.7 | 271.5 |
| 106 | 15.3 | 16.4 | 17.8 | 19.4 | 21.3 | 23.6 | 26.4 | 30.1 | 35.0 | 41.7 | 51.6 | 67.7 | 98.5 | 180.7 |
| 108 | 14.8 | 15.9 | 17.2 | 18.7 | 20.4 | 22.5 | 25.2 | 28.5 | 32.8 | 38.6 | 47.0 | 60.1 | 83.2 | 135.2 |
| 110 | 14.4 | 15.4 | 16.6 | 18.0 | 19.6 | 21.6 | 24.0 | 27.0 | 30.9 | 36.0 | 43.2 | 54.0 | 72.0 | 108.0 |
| 112 | 14.0 | 15.0 | 16.1 | 17.4 | 18.9 | 20.7 | 22.9 | 25.7 | 29.1 | 33.6 | 39.9 | 49.0 | 63.4 | 89.5 |
| 114 | 13.6 | 14.5 | 15.6 | 16.8 | 18.2 | 19.9 | 22.0 | 24.5 | 27.6 | 31.6 | 37.1 | 44.8 | 56.6 | 76.9 |
| 116 | 13.3 | 14.1 | 15.1 | 16.3 | 17.6 | 19.2 | 21.1 | 23.3 | 26.2 | 29.8 | 34.6 | 41.3 | 51.1 | 67.1 |
| 118 | 12.9 | 13.7 | 14.7 | 15.8 | 17.0 | 18.5 | 20.2 | 22.3 | 24.9 | 28.2 | 32.5 | 38.3 | 46.6 | 59.6 |
| 120 | 12.6 | 13.4 | 14.3 | 15.3 | 16.5 | 17.8 | 19.5 | 21.4 | 23.8 | 26.7 | 30.6 | 35.7 | 42.8 | 53.5 |
| 122 | 12.3 | 13.0 | 13.9 | 14.8 | 15.9 | 17.2 | 18.7 | 20.5 | 22.7 | 25.4 | 28.9 | 33.4 | 39.6 | 48.5 |
| 124 | 12.0 | 12.7 | 13.5 | 14.4 | 15.4 | 16.7 | 18.1 | 19.7 | 21.8 | 24.2 | 27.3 | 31.4 | 36.8 | 44.4 |
| 126 | 11.7 | 12.4 | 13.1 | 14.0 | 15.0 | 16.1 | 17.4 | 19.0 | 20.9 | 23.1 | 26.0 | 29.6 | 34.3 | 40.9 |
| 128 | 11.4 | 12.1 | 12.8 | 13.6 | 14.5 | 15.6 | 16.9 | 18.3 | 20.0 | 22.1 | 24.7 | 27.9 | 32.2 | 37.9 |
| 130 | 11.2 | 11.8 | 12.5 | 13.2 | 14.1 | 15.1 | 16.3 | 17.7 | 19.3 | 21.2 | 23.6 | 26.5 | 30.3 | 35.3 |
| 132 | 10.9 | 11.5 | 12.2 | 12.9 | 13.7 | 14.7 | 15.7 | 17.1 | 18.6 | 20.3 | 22.5 | 25.2 | 28.6 | 33.1 |
| 134 | 10.7 | 11.2 | 11.9 | 12.6 | 13.4 | 14.3 | 15.3 | 16.5 | 17.9 | 19.6 | 21.6 | 24.0 | 27.1 | 31.0 |
| 136 | 10.4 | 11.0 | 11.6 | 12.3 | 13.0 | 13.9 | 14.8 | 16.0 | 17.3 | 18.8 | 20.7 | 22.9 | 25.7 | 29.2 |

EXAMPLE.—If the temperature of the injection water supplied to a condenser is 70° F. and the temperature of the discharge 110°, how many units weight of injection water will be required per unit weight of steam condensed?

SOLUTION.—In this case, by applying the rule, $\frac{1,190 - 110}{110 - 70} = 27$, that is, the weight of the injection water required will be 27 times the weight of the steam exhausted into the condenser. Ans.

**69.** Table IV shows the quantity of cooling water required under specific temperature conditions. The values in this table are based on the rule given in Art. **68.**

## COMPARATIVE COST OF OPERATING CONDENSERS

**70.** From the saving estimated to be derived by the use of condensers should be deducted the interest on the extra investment, the cost of maintenance, and the cost of operating the air and circulating pumps; therefore, if the power for this pumping can be derived direct from the condensing engine, the cost is the least, as the prime mover is the most economical source of power. If the pumps are operated by an electric motor, the cost is slightly increased because the efficiency is less, on account of the intermediary of the motor, than from the engine direct. A centrifugal pump will be found quite satisfactory only with certain types of condensers, and may be driven by a motor or small engine. If the pumps are independently steam driven, the cost is greater, but some heat may be saved by using their exhaust steam for heating feedwater.

**71. Methods for Operating Pumps.**—The air and circulating pumps are usually combined, and the methods of drive are stated in the order of their economy.

The following is the estimated steam in pounds per horsepower-hour for pumping:

| | |
|---|---|
| *a*, by belt from engine shaft | 16 |
| *b*, in a large station by a high economy pumping engine | 20 |
| *c*, by an electric motor | 30 to 40 |
| *d*, by compound steam cylinders on pumps | 40 to 70 |
| *e*, by a direct steam cylinder | 100 to 150 |

Fig. 30 shows the arrangement of a Knowles jet condenser with a triplex motor-driven pump.

**72. Limit of Condensation.**—The theoretical limit of condensation would be that of absolute vacuum, which is equivalent to 29½ inches of mercury or 14¾ pounds per square inch at sea level. In actual practice, with condensers, this cannot be attained, but the vacuum may range from 23 to 27 inches, or 11½ to 13½ pounds.

**73. Relative Vacuum.**—A perfect vacuum cannot be attained for the reason that the cooling water entering the condenser immediately absorbs the heat from the exhaust steam and a vapor is formed, thus preventing a perfect vacuum. The ratio between the temperature of condenser discharge and the vacuum maintained under good conditions is as follows:

| | |
|---|---|
| 00 inches vacuum 212° F. | 25 inches vacuum 135° F. |
| 11 inches vacuum 190° F. | 27½ inches vacuum 112° F. |
| 18 inches vacuum 170° F. | 28½ inches vacuum 92° F. |
| 22½ inches vacuum 150° F. | |

Twenty-five inches vacuum is considered a point of good efficiency.

## COOLING TOWERS

**74.** The **cooling tower** is a device whereby the water discharged from a condenser may be reduced in temperature by exposure, in the form of spray, drops, or minute streams, to strong currents of air, and thereby sufficiently cooled to be again used in the condenser; the repeated cooling by passing through the tower and circulation through the condenser renders possible the continuous use of the same body of water. The mechanical subdivision and distribution of the water for cooling is obtained by different methods; such as passing it over suspended galvanized-wire mats, over many courses of thin vertical boards laid up like cribwork, or over many series of thin pipes. As early as 1676, the rudiments of our modern cooling tower are known to have been used in Hindustan. An early English traveler describes

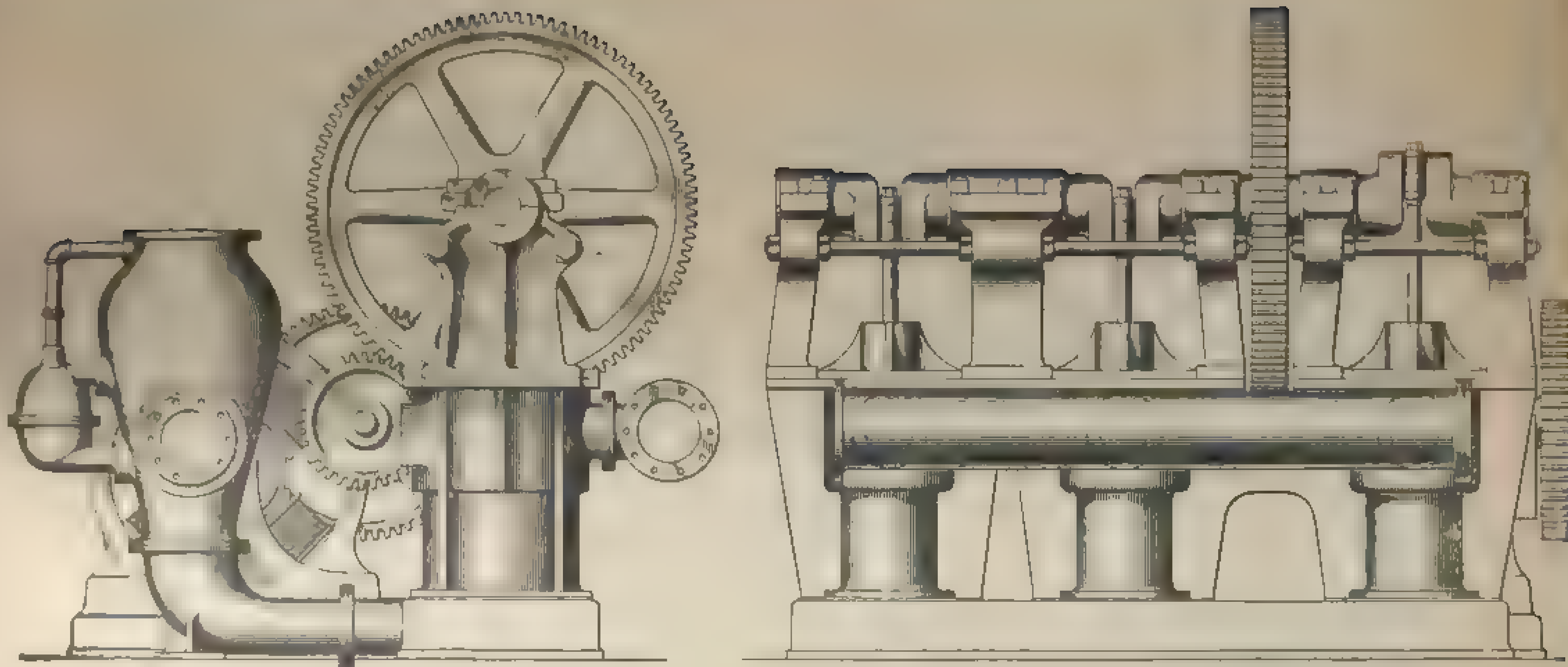

FIG. 30

an apparatus formed of bamboo tubes and mats of palm leaves, by which the Indian grandees used to cool the water for their baths. The water was slowly poured over the cooling mats, and drained below into a stone basin. The evaporation was effected by means of fans operated by hand.

**75. Vaporization of the Cooling Water.**—When water is freely exposed to the atmosphere, as in passing through a cooling tower, the stratum of air in contact with its surface becomes more or less charged with vapor. As evaporation takes place only from the exposed surface, the amount of vapor must therefore depend on the extent of the surface of water exposed to the air. Moderately dry air absorbs moisture, at first rapidly, but as it becomes saturated, the process proceeds more and more slowly, and finally ceases. Evidently, therefore, the more rapidly the air is circulated, the more rapidly evaporation proceeds. The capacity of air for carrying moisture increases in proportion to the temperature. At 202°, saturated air holds about 100 times the weight of water that would saturate air at 32°. For each temperature there is a maximum of density, and hence of pressure, that the vapor exerts, and it is found that the rate of evaporation at different temperatures is proportional to the differences of the elastic forces of the vapor at the surface of the liquid, and that of the vapor actually present in the surrounding air.

**76.** It is therefore evident that the efficiency of a cooling tower depends: (*a*) on the extent of the exposed water surfaces; (*b*) on the volume of air brought into contact with the exposed water surfaces and the rapidity of the air circulation; (*c*) on the difference of the pressure of vapors at the water surface, and that in the air—which is regulated by the accidental conditions of water and air as to temperature at the time of contact, and percentage of moisture—all three controlling the conditional rate of evaporation. The efficiency of any cooling tower must, therefore, be largely due to the uniform and perfect distribution of the water in fine spray or fine films as it passes through the tower. The more

perfectly the water is subdivided, permitting the air to come in through contact therewith, the better efficiency will be attained in the tower.

**77. Loss of Water by Evaporation.**—The loss of water due to evaporation depends on the degree of heat extracted. As in every pound of water converted into vapor about 1,000 units of heat become latent, the loss evidently must be proportional to the total amount of heat thus absorbed and carried off, and consequently must depend on the difference of the temperature between the hot and cooled liquid, or in other words, on the degree to which the water has been cooled. If 100,000 pounds of water is cooled from, say, 130° to 70°, 60 units of heat have been absorbed from every pound, or a total of 6,000,000 units; and as in every pound of steam 1,000 units of heat become latent, 6,000 pounds, or 6 per cent., of the liquid will be evaporated. The loss of this small percentage of water by vaporization is a necessity, and must be estimated as one of the items of cost and will vary from 3 to 7 per cent.

It is clear that the quantity lost by evaporation and the reduction of temperature attained depends on the relative humidity in the atmosphere, because on this condition depends its readiness to absorb additional vapor; hence, with dry air the cooling will be more effective than with a high degree of humidity. This is shown in Table V, which gives the results taken from a test record during the operation of a pair of towers.

**78. Reduction of Temperature.**—The amount of heat extracted from the condenser discharge passing through the cooling tower will vary according to the atmospheric temperature, the surface over which the water is exposed, and the volume and velocity of the air passing through the tower; the reduction in temperature will vary from 30° to 45°, and with a sufficient volume of water in circulation, a vacuum of from 23 to 25 inches of mercury may be obtained. As the total water consists of the condensed steam from the boilers plus the circulating water, it will be necessary to add, from

time to time, a sufficient amount of fresh water to replace the loss caused by evaporation. It will thus be seen that a plant can operate almost entirely independent of a city water supply. With any cooling tower, where the feedwater for the boilers is taken from that circulating through the tower, it will be necessary to utilize one or more of the best types of grease extractors to remove the oil before the water is pumped into the boilers.

TABLE V

RESULTS OF TESTS ON COOLING TOWERS

| | First Test | Second Test | Third Test | Fourth Test |
|---|---|---|---|---|
| Temperature of air entering tower, degrees Fahrenheit | 54.70 | 85.70 | 84.60 | 87.00 |
| Atmospheric humidity, per cent. | 37.50 | 51.00 | 63.00 | 42.60 |
| Temperature of water delivered to tower, degrees Fahrenheit | 134.50 | 135.20 | 136.40 | 135.25 |
| Temperature of water leaving tower, degrees Fahrenheit | 94.90 | 104.20 | 101.60 | 90.75 |
| Number of degrees Fahrenheit water was cooled | 39.60 | 31.00 | 34.80 | 44.50 |
| Pounds of water supplied to tower | 12,531 | 12,508 | 10,713 | 6,304 |
| Pounds of water lost by evaporation while passing through tower | 424 | 363 | 341 | 263 |

**79. Air Circulation.**—Three methods for obtaining air circulation through cooling towers are commonly used:

1. Those in which the air is forced in rapid circulation through the tower by means of a fan blower, which discharges fresh air into the lower part of the tower, whence it is deflected upwards through the film or spray of condensing water.

2. Those in which a chimney or vertical flue, rising from 50 to 100 feet above the cooling compartment of the tower, creates sufficient natural draft to draw a large volume of air through the cooling compartment, and allows the vapor from the cooling water to be carried off from the top of the

chimney. This type of tower entirely avoids cost for daily operation of fans.

3. Where the ground space is sufficient, the cooling surface of the tower is distributed over a larger area, allowing free circulation of the air naturally through the tower; this also avoids the use of any mechanical means to circulate the air, and saves the cost of driving fans.

## EXAMPLES OF COOLING TOWERS

**80. The Barnard-Wheeler Cooling Tower.**—In this tower, shown in Fig. 31, the water is cooled by allowing it to flow over suspended galvanized-wire mats. The casing is usually made of steel plates. The pump discharge is led to the top of the tower and the warm water is there distributed by a suitable system of piping to the upper edges of the mats, over the surface of which it spreads in thin films, compelling a partial interruption of the flow and continuously bringing new portions of the water to the surface, thereby exposing it to the evaporating and refrigerating effects of the air-currents. To assist the cooling action, the air in immediate contact with the water is set in rapid circulation by means of the fan blowers $a, a'$, Fig. 31, which force air into the lower part of the tower and upwards between the mats.

**81. The Worthington Cooling Tower.**—In this tower, shown in Fig. 32, the water runs over the inside and outside surfaces of a large number of cylindrical tubular tiles $c, c', c''$, which rest on a grating $d$ supported by a brick wall $e$ extending around the circumference of the tower. The warm discharge water from the condenser enters the tower through the pipe $f$, passes up the central pipe $g$, and is delivered on the upper layer of tiling and over the whole cross-section of the tower by the distributing device $h$, which consists of four pipes, radiating from the central pipe $g$, which are caused to revolve about the central pipe by the reaction of jets of water issuing from perforations on one side of each pipe. The water thus delivered spreads over the outside and inside

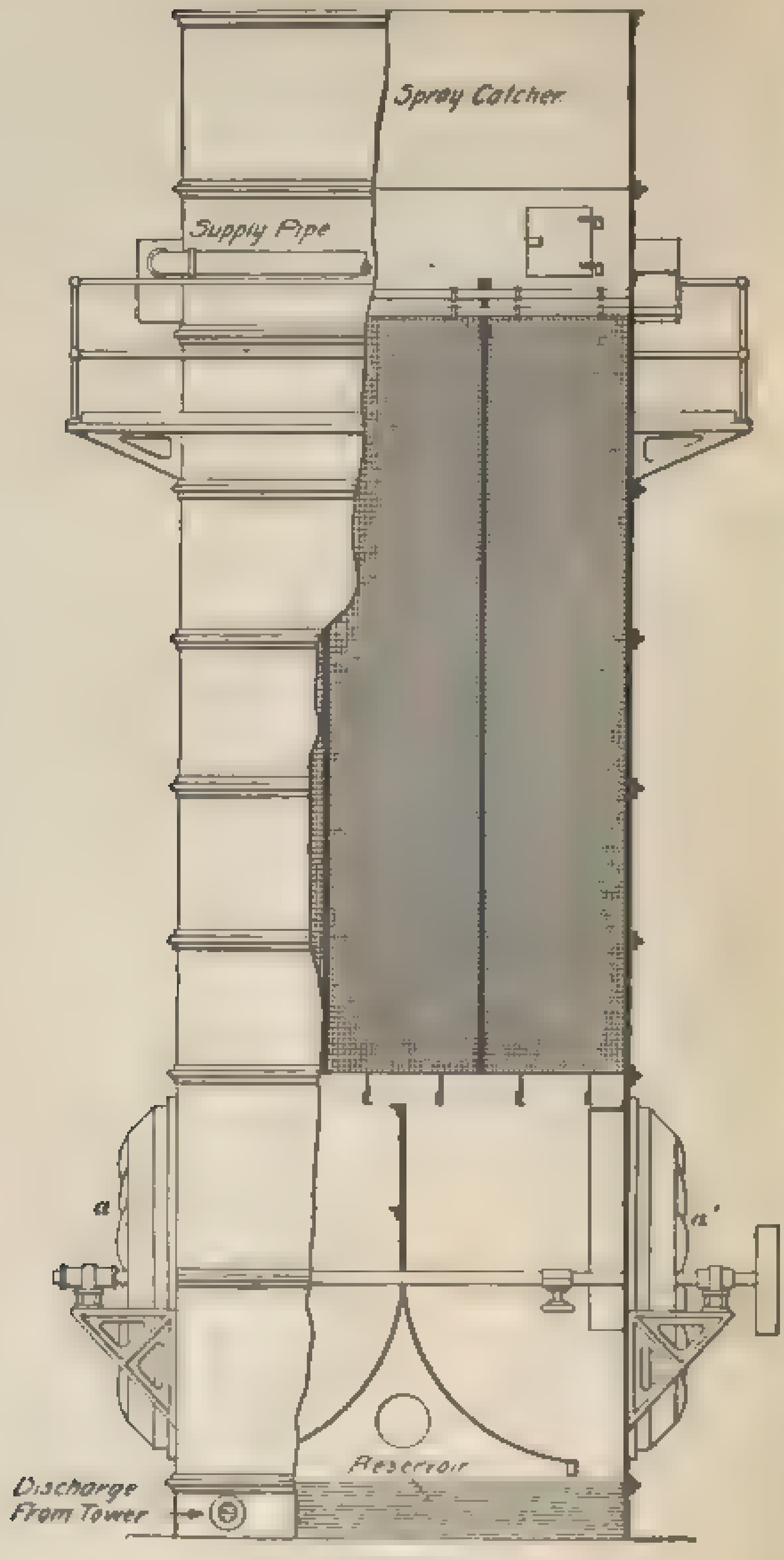
Spray Catcher
Supply Pipe
a
a'
Reservoir
Discharge
From Tower

FIG. 31

surfaces of the walls of the tiling and forms a continuous sheet, which is presented to the action of the air. The air is circulated by the fan *b*, driven by a small engine or electric motor. The air drawn in by the fan is deflected upwards by the plate *l*. The cooled water collects in the reservoir *i*, from which it is drawn off through the pipe *j*, *m* is a manhole to give access for inspection or repairs. Fig. 33 shows a fan-cooled tower as installed in relation to the engine and condenser.

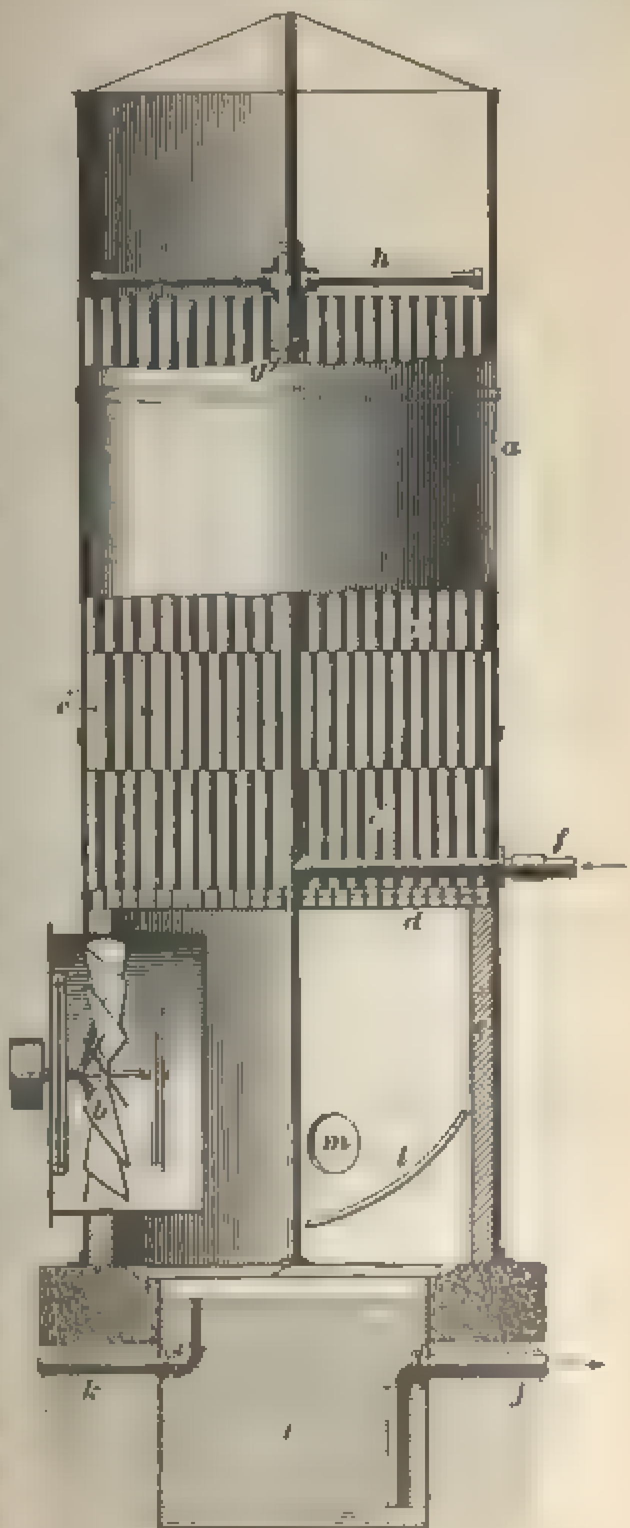


FIG. 32

**82. Barnard's fanless self-cooling tower** is shown in Fig. 34. In this device the use of mechanical means for circulating air for cooling the water is dispensed with, thus avoiding the wear and tear and the expenditure of power that are always associated with moving parts. The hot circulating water discharged from the condenser is pumped up through the central stand pipe *a*, from which it is led to the trough *b* and distributing pipes *c*, *c*, causing a constant flow of thin films of water over the meshes of the wire mats *d*, *d'*, and finally draining into the tank or reservoir *f* forming the foundation of the tower,

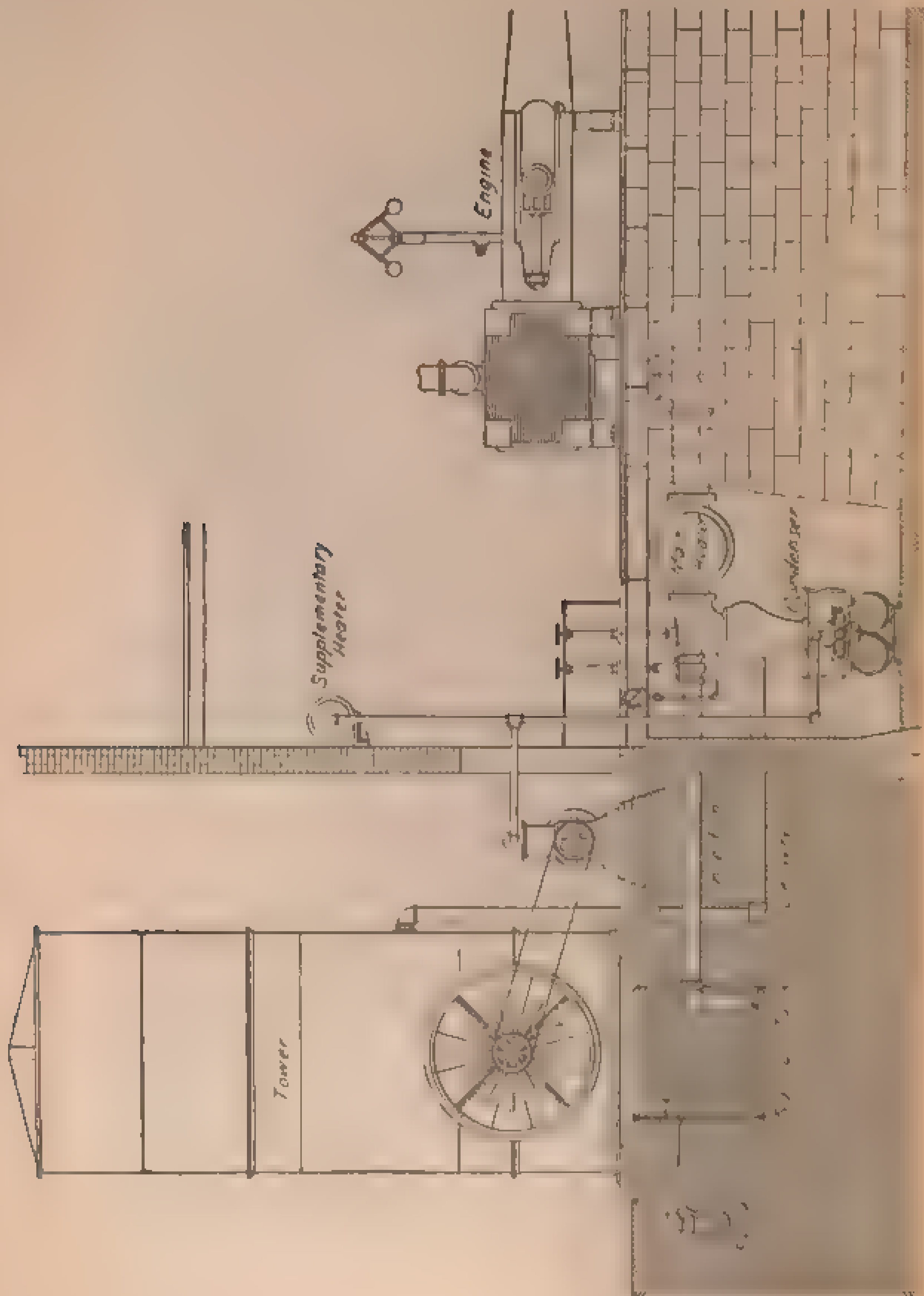


FIG. [illegible]

from whence the cooled water is returned through the injection pipe *c* for use again in the condenser.

The mats are placed radially and are entirely exposed to the atmosphere; they are so arranged as to permit the air

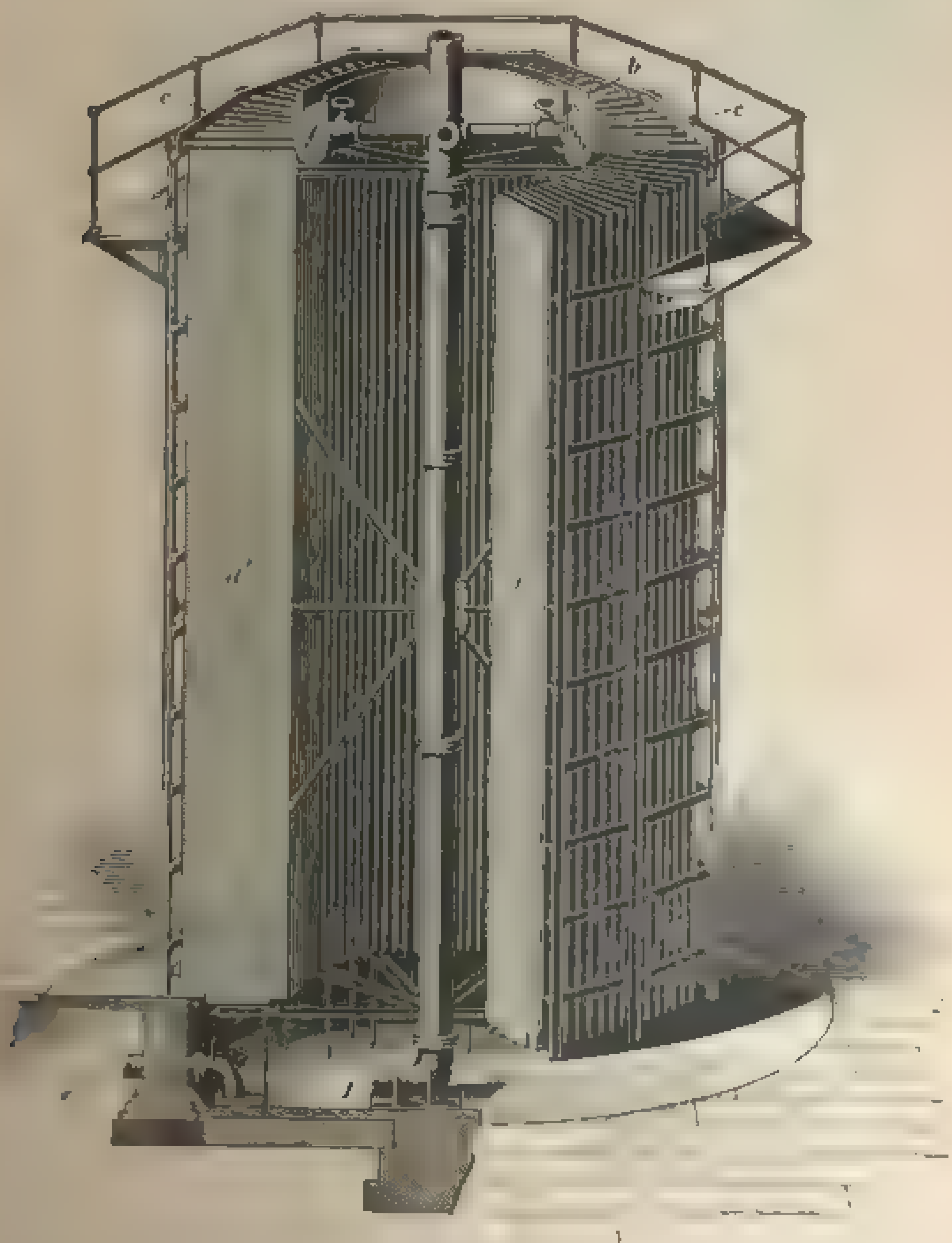

FIG. 34

to come into contact with the descending films of water by natural circulation, and the consequent evaporation is carried far enough to reduce the temperature of the injection water to a sufficiently low degree for condensing purposes.

**83.** **The Stocker cooling tower** is a structure built of wood, steel, or brick, according to circumstances. The cooling surfaces are built up of checkerwork or crosspieces of boards in horizontal layers set at right angles to one another. At the intersections are placed upright partitions diagonally across the square openings between the boards. The construction of this tower will be understood by referring to Fig. 35, where (*a*) is a plan view looking down on the latticework, (*b*) shows the crosspieces at right angles to each other, and (*c*) shows the upright diagonal partitions.

The water is pumped to the top of the tower and trickles down over these surfaces in thin films, which are broken up in falling at each intersection of the boards, and the water is thus brought into contact with the current of air that passes upwards through the tower. The air circulation may be set up by fans, or if the tower is made high enough natural draft may be used.

**84.** **Location of Cooling Towers.**—Cooling towers may be located in rear yards or on the roof of one of the power-station buildings, if ground space is not available. Where a large plant is to be provided for, a sufficient number of cooling towers may be erected in a battery with the piping so arranged that one or more towers may be operated as desired, according to the load.

**85.** **Advantages of Cooling Towers.**—The advantages that the addition of the cooling tower afford to an electric power station are that it may be possible to select a location for building the station more favorable to economy in the cost of copper for the system of distribution, and with highly desirable facilities for securing coal. Other advantages are, less coal consumed for the same power developed or more power for the same consumption of coal; saving in water by using the condensed steam for boiler-feed purposes; less boiler capacity necessary for a given amount of engine horsepower.

The knowledge that the results attained with condensers used in connection with cooling towers are practically the

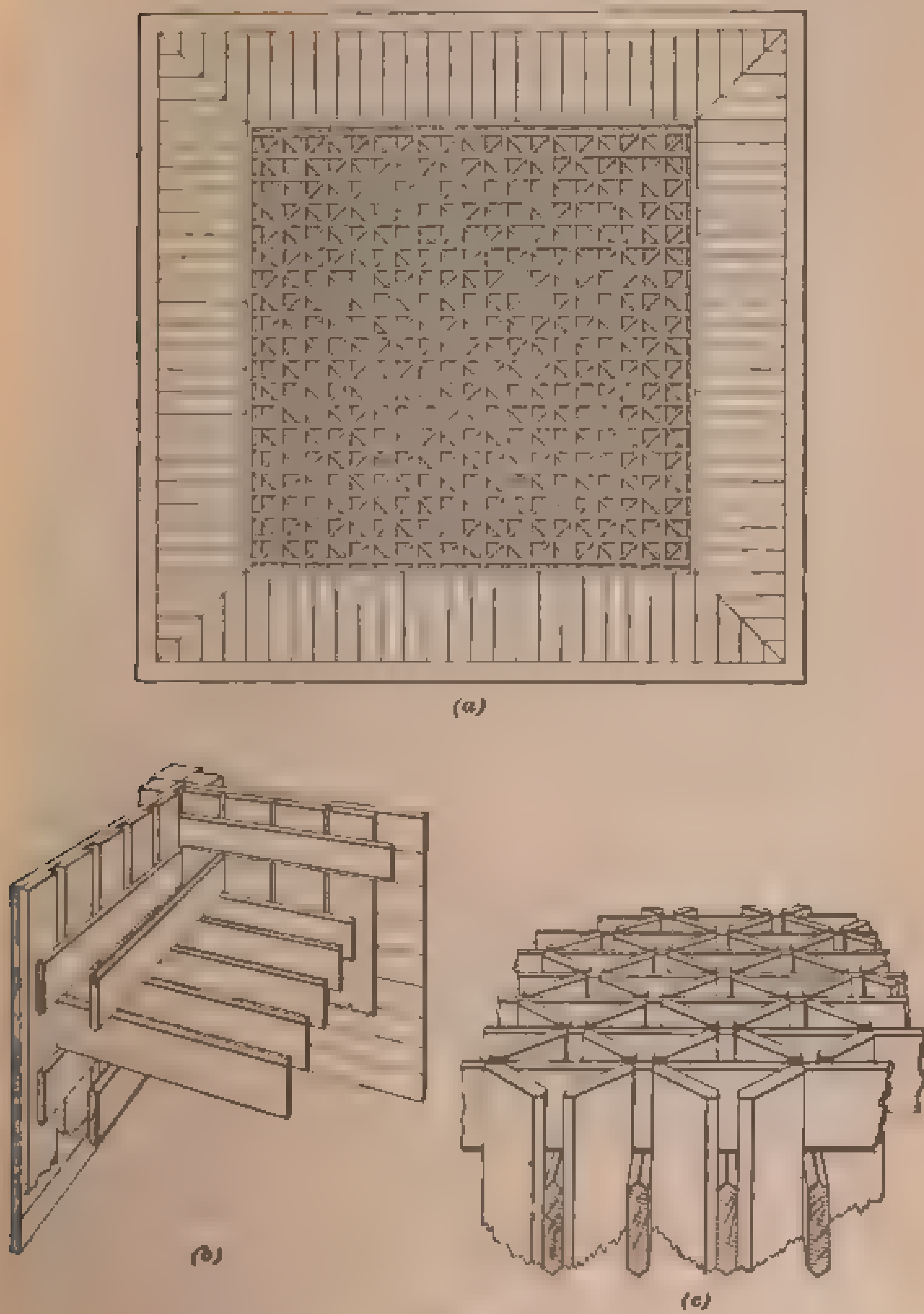

FIG. 35

same as those using water from the natural source of supply, makes it reasonable to recognize the operative advantages of the cooling tower. Stations that are located so as to secure circulating water from the natural source of supply are frequently interfered with by ice, low water, or an excessive rise in the river. The cooling tower has none of these disadvantages.

The conditions under which the use of a cooling tower should be carefully considered are: (*a*) Where there is a uniform load of, say, 300 horsepower, or upwards, for several hours, such as a street-lighting load all night; (*b*) where the cost of coal is, say, $2.50 per ton, or upwards; (*c*) where boiler feedwater costs from $25 per month, up.

As an illustration of the saving effected by the use of a compound engine in conjunction with a condenser and cooling tower in place of a simple non-condensing engine, the following example may be given: An $18\frac{1}{2}'' \times 30''$ medium high-speed engine was tested several times for its steam consumption, and found under constant load to use an average of 46.8 pounds of steam per horsepower-hour at 97.4 pounds average boiler pressure per square inch. The high-pressure cylinder was removed and a $14\frac{1}{4}'' \times 25'' \times 30''$ tandem compound cylinder put on. The steam consumption then proved to be 16.5 pounds per indicated horsepower-hour with 110 pounds pressure on the same boilers as in the first test.

It is desirable (but not essential) to use a surface condenser in conjunction with a cooling tower, as with this type of condenser there will be the minimum duty required of the pump, the work being only due to the height of the tower, as the ascending and descending columns of water will balance each other below the tower reservoir. Where a cooling tower is used in connection with a surface condenser with air and circulating pumps, the power required for operating the tower and pumps will be from $2\frac{1}{2}$ per cent. to 4 per cent. of the total indicated horsepower of the engines, much depending on the size of the engines. The large engine will be the more economical, and the fanless type of cooling tower will require the least power for its operation.

# ELECTRIC POWER STATIONS

## (PART 4)

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## PIPE FITTING

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### LOSS OF PRESSURE IN PIPING

**1.** The proper designing of a system of **pipe fitting** for an electric power station requires a careful analysis of the conditions of service, a thorough knowledge of the methods for distributing and conveying steam and water, and of the quality and strength of materials employed. When steam leaves the boilers and starts to flow through a pipe of given diameter, several factors tend to change the form of the original energy possessed by the steam; among them are:

(*a*) **Condensation,** which may be divided into two parts—*static condensation,* which occurs when the steam fills the pipe, but is not flowing through it; and *dynamic condensation,* which takes place when a valve is opened permitting the steam to flow through the pipes. The latter should be less than the former, because of the fall in pressure and temperature that takes place at the delivery end of the pipe and the effort that is being constantly made to raise or maintain the original condition of the steam; but it is found that the amount of condensation is very nearly equal in both cases.

(*b*) **Friction** in the pipe causes a loss of pressure and requires work to be done to overcome the loss. The natural condition of condensation, combined with the loss in pressure, due to friction, cannot be wholly overcome; no

matter to what extent the piping be covered with the best qualities of non-conducting covering there is still a loss of heat units.

(*c*) **Expansion** causes a change in the external latent energy, which is accounted for in the steam tables under different absolute pressures.

In horizontal pipes, there is less tendency to change the form of energy possessed by the steam than when flowing through inclined or vertical pipes. The force of gravity must be considered when long vertical pipes are required through which the steam will flow upwards or downwards; this will be readily understood when consideration is given to the number of pounds of water in the form of steam to be transferred per hour.

**2. Loss of Pressure by Friction.**—Friction is greater through elbows of short radius than through elbows of long radius. Globe valves offer a serious impediment to the passage of steam, but the drop in pressure when passing through a gate valve is practically negligible. The loss of head due to getting up the velocity and caused by the friction of the steam entering the pipe and passing elbows and valves will reduce the flow below the estimated capacity of straight pipes. The resistance at a globe valve is about the same as that for a length of pipe equal to 114 diameters divided by a number represented by 1 + (3.6 ÷ diameter). For example, a 3-inch globe valve would introduce as much friction as $\frac{114 \times 3}{1 + \frac{3.6}{3}} = 155$ feet of 3-inch pipe. The resistance at an elbow is approximately equal to two-thirds that of a globe valve. These equivalents—for openings, for elbows, and for valves—must be added in each instance to the actual length of the pipe, if the loss due to friction is to be calculated closely.

The rigid requirements of reliable and continuous operation of power stations have, within the past few years, revolutionized the simple methods of piping of earlier

construction to a large degree, and have resulted in a great improvement in the design and quality of all the materials and fittings requisite for a complete system.

### MOVEMENT OF STEAM

**3.** In preparing the plans for a system of piping it is essential to know not only the quantity of steam that must be transferred between the source of supply at the boiler and the points of demand at the engines, but also the quantity of steam that will flow through pipes of given diameters. The velocity of steam passing freely from one vessel into another is equal to the velocity of a body that has fallen through a distance equal to the difference in height of two columns of steam of 1 square inch cross-section, the entire weight of one column equaling the pressure per square inch in one vessel and the entire weight of the other column equaling the pressure per square inch in the other vessel, the density of steam being uniform and equal to that due to the heavier pressure.

EXAMPLE.—What will be the velocity of steam at 16 pounds pressure, absolute, passing into a steam of 15 pounds absolute?

SOLUTION.—The weight of a cubic foot of steam at 16 pounds absolute is .04111 lb. (see steam table), this divided by 144 = .0002855, which is the weight of a column of steam of 1 sq. in. cross-section and 1 ft. high. The total height due to 16 lb. pressure, therefore, is 16 ÷ .0002855 = 56,040 ft., and at 15 lb. $\frac{15}{16}$ of 56,040 = 52,540 ft. The difference in the height of columns, therefore, is 56,040 − 52,540 = 3,500 ft. In falling 3,500 ft., a body will acquire a velocity of 474 ft. per sec., which is the velocity of steam at 16 lb. pressure flowing into steam of 15 lb. pressure per square inch. The velocity, 474 ft. per sec., is obtained from the formula for falling bodies $v = \sqrt{2gh}$. $\sqrt{2g} = 8.02$ and $h = 3,500$, hence, $v = 8.02 \times \sqrt{3,500} = 474$ ft. per sec. Ans.

**4. Flow of Steam Under Pressure.**—The amount of steam that will flow through a pipe of given diameter in 1 minute at specified pressures may be calculated by the following formula:

$$W = 87\sqrt{\frac{D(p_1 - p_2)d^5}{L\left(1 + \frac{3.6}{d}\right)}} \qquad (1)$$

where $W$ = weight of steam discharged, in pounds, per minute;

$D$ = density of steam, weight per cubic foot, at initial pressure $p_1$;

$p_1$ = initial pressure;

$p_2$ = final pressure;

$L$ = length of pipe, in feet;

$d$ = diameter of pipe, in inches.

The difference $p_1 - p_2$ is equal to the drop in pressure in the pipe. If we consider the drop in pressure through the pipe to be 1 pound and the length $L$ to be 100 feet, we have

$$W' = 87\sqrt{\frac{D \times d^5}{100\left(1 + \frac{3.6}{d}\right)}} = 8.7\sqrt{\frac{D \times d^6}{d + 3.6}} \qquad (2)$$

where $W'$ = weight, in pounds, of steam delivered per minute through 100-foot lengths of pipe.

EXAMPLE.—How many pounds of steam per minute can be delivered through a 3-inch pipe with an initial pressure, as shown by the steam gauge, of 100 pounds, if the loss of pressure in the pipe is 1 pound?

SOLUTION.—If the gauge pressure is 100 lb. per sq. in., the absolute pressure must be $100 + 14.7 = 114.7$. A cubic foot of steam at this pressure will weigh, approximately, .263 lb., $d = 3$ in., $d^6 = 729$ and

$$W' = 8.7\sqrt{\frac{.263 \times 729}{3 + 3.6}} = 46.7 \text{ lb. per min. Ans.}$$

These formulas for the flow of steam through pipes, like all similar formulas, give approximate results only, but the results are near enough for practical purposes. The actual inside diameter of pipe is very rarely the same as the nominal diameter, and it is seen from formula **1** that a slight change in the diameter has a great influence on the flow of steam. Table I gives the approximate weights of steam delivered per minute through 100 feet of pipe of various diameters with a drop in pressure of 1 pound. On the whole, these values are slightly higher that those given by formula **1.**

If the allowable drop in pressure is to be other than 1 pound, multiply the values given in the table by the square root of the drop. If the length is other than 100 feet, divide

## TABLE I

WEIGHT OF STEAM DELIVERED PER MINUTE THROUGH 100 FEET OF PIPE FOR STANDARD PIPE SIZES AND VARIOUS INITIAL PRESSURES

| Initial Pressure by Gauge | Nominal Inside Diameter of Pipe, in Inches | | | | | | | | | | Initial Pressure by Gauge |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 3 | 3½ | 4 | 4½ | 5 | 6 | 7 | 8 | 9 | 10 | |
| | Weight, in Pounds, of Steam Delivered per Minute Through 100 Feet of Pipe With 1 Pound Loss of Pressure | | | | | | | | | | |
| 70 | 43.2 | 64.5 | 91.7 | 124.3 | 168.7 | 277.2 | 410.5 | 577.2 | 793.3 | 1,051.7 | 70 |
| 80 | 45.5 | 68.0 | 96.6 | 130.9 | 177.7 | 292.1 | 432.5 | 608.2 | 835.8 | 1,108.4 | 80 |
| 90 | 47.6 | 71.2 | 101.2 | 137.2 | 186.3 | 306.0 | 453.3 | 637.3 | 875.9 | 1,161.3 | 90 |
| 100 | 49.7 | 74.3 | 105.7 | 143.2 | 194.4 | 319.8 | 473.0 | 665.1 | 914.1 | 1,211.8 | 100 |
| 110 | 51.7 | 77.3 | 109.9 | 148.9 | 202.1 | 332.2 | 491.8 | 691.5 | 950.4 | 1,259.9 | 110 |
| 120 | 53.6 | 80.2 | 113.9 | 154.4 | 209.5 | 344.3 | 509.9 | 717.0 | 985.4 | 1,306.3 | 120 |
| 130 | 55.4 | 82.9 | 117.8 | 159.7 | 216.7 | 356.1 | 527.4 | 741.6 | 1,019.6 | 1,351.1 | 130 |
| 140 | 57.2 | 85.5 | 121.5 | 164.7 | 223.6 | 367.4 | 544.6 | 765.7 | 1,052.9 | 1,393.9 | 140 |
| 150 | 58.9 | 88.1 | 125.2 | 169.6 | 230.2 | 378.3 | 560.2 | 787.7 | 1,082.6 | 1,428.1 | 150 |

100 by the length in feet and multiply the figures in the table by the square root of the quotient.

EXAMPLE.—How many pounds of steam will be discharged per minute, with 120 pounds initial gauge pressure, through a pipe 3 inches in diameter and 400 feet long, the allowable loss of pressure being 2 pounds?

SOLUTION.—From Table I, the amount discharged through 100 ft. of 3-in. pipe for a loss of 1 lb. is 53.6 lb. per min. for an initial pressure of 120 lb. With a loss of 2 lb. pressure the amount discharged will be $53.6 \times \sqrt{2}$. For a length of 400 ft. the discharge will be $53.6 \times \sqrt{2} \times \sqrt{\frac{100}{400}} = 37.9$ lb. per min. Ans.

**5. Comparative Economy of High-Pressure Steam.** When contemplating the use of steam at high pressures the actual gain in engine economy is worthy of close consideration. Table II shows the steam consumption of a perfect engine; i. e., an engine devoid of friction and which utilizes all the energy in the steam liberated by expanding from boiler pressure to the pressure of the exhaust. The table shows the steam consumption per indicated horsepower per hour for boiler pressures ranging from 100 to 250 pounds.

TABLE II

STEAM CONSUMPTION OF PERFECT ENGINE AT VARIOUS STEAM PRESSURES

| Boiler Pressure by Gauge Pounds | Temperature Degrees Fahrenheit | Pounds Steam per Indicated Horsepower per Hour | |
|---|---|---|---|
| | | Non-Condensing | Condensing |
| 100 | 337.6 | 16.24 | 7.71 |
| 125 | 352.6 | 14.71 | 7.37 |
| 150 | 365.6 | 13.63 | 7.09 |
| 175 | 377.1 | 12.81 | 6.87 |
| 200 | 387.6 | 12.16 | 6.68 |
| 250 | 405.9 | 11.19 | 6.39 |

It is at once seen that there is no gain beyond 200 pounds pressure sufficient to compensate for the extra costs incurred throughout the entire construction.

## PRINCIPAL REQUIREMENTS OF THE STEAM-PIPING SYSTEM

**6.** A system of steam piping for an electric power station must be so designed as to insure reliability of service, economy of construction, and minimum of loss during transmission. The main lines of piping must be so interconnected that blow-outs will not cripple or derange the working of the plant. This continuity of operation is absolutely indispensable to a successful station.

The pipes and fittings must be so proportioned as to permit a free flow of the steam, water, etc., and so that undue loss shall not be caused by condensation, radiation, or friction. The steam piping should be so arranged that water pockets will be avoided, and where unavoidable they must be dripped free from water; the entrained water can be automatically returned to the boiler. By-pass pipes, with suitable placing of valves, should be arranged around feedwater heaters, economizers, pumps, etc. The system must be so designed as to give perfect freedom for expansion and

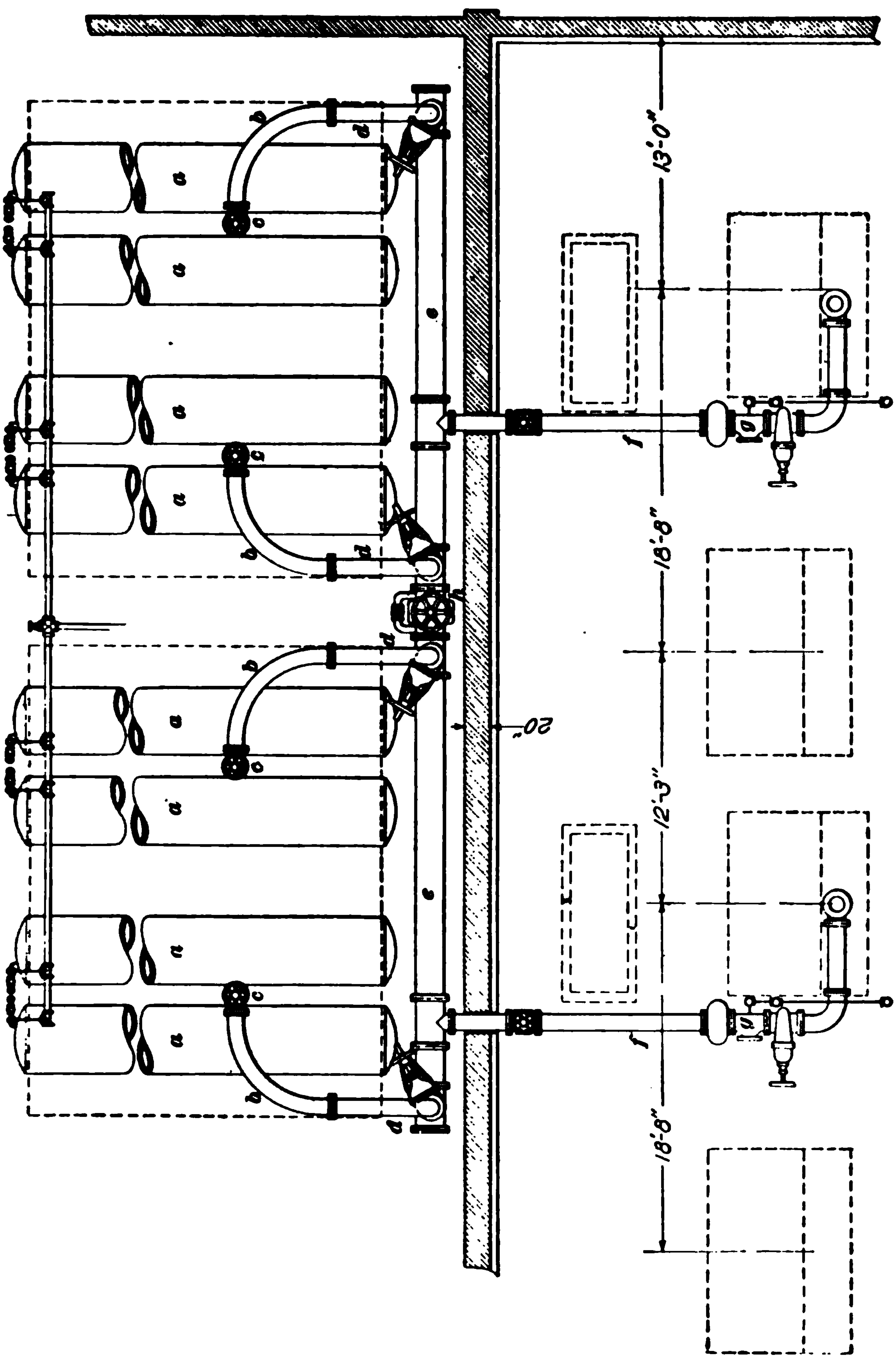


FIG. 1

contraction, without undue strain on any member of the system, and without opening joints that will cause leakage.

**7.** Perfect drainage must be provided to the end that all waters of condensation shall be fully separated from the steam, and by suitable traps or return systems delivered back to the boiler. The elaborate duplication of steam

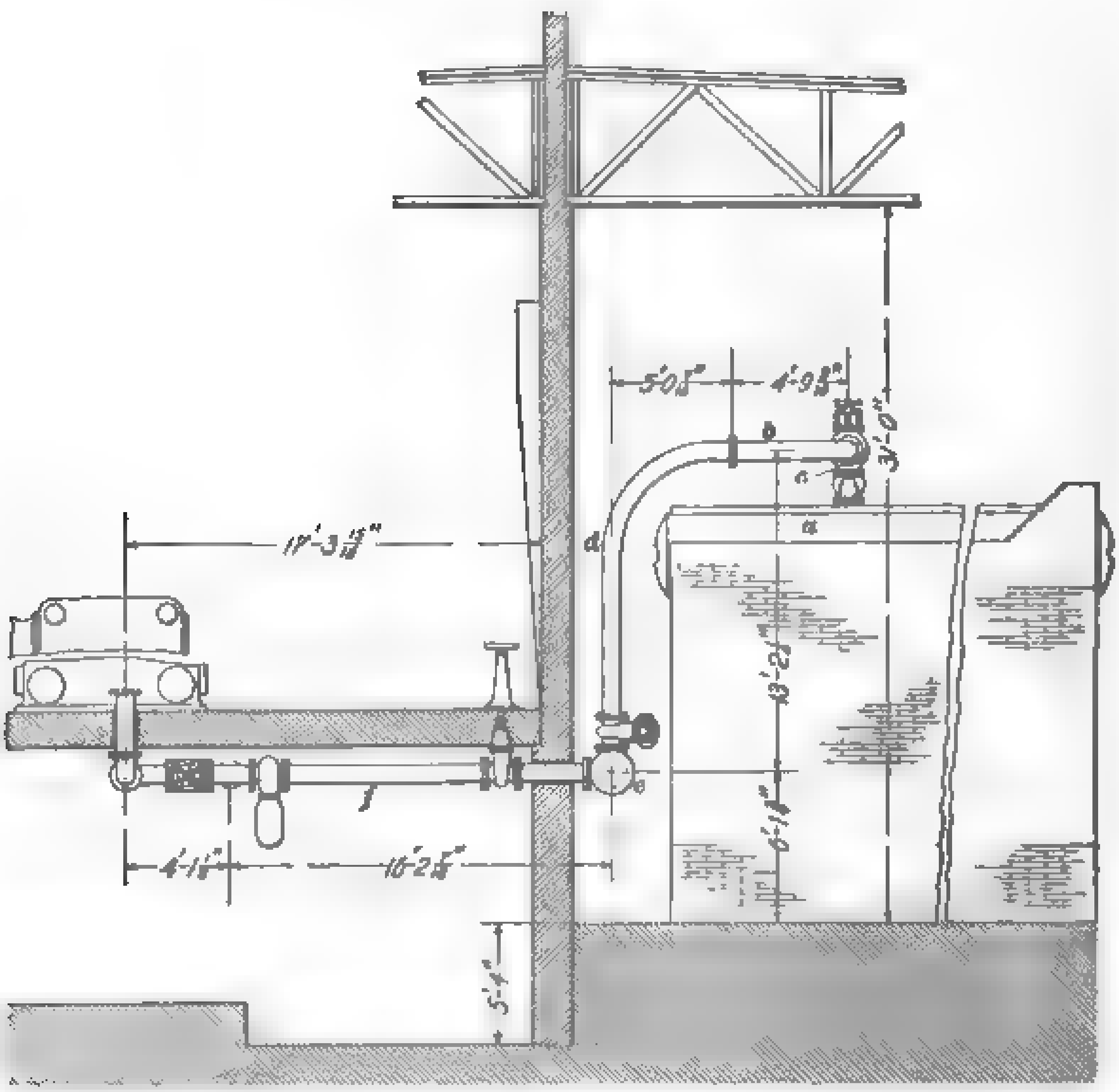

FIG. 2

mains and connections is not necessary. The double or duplicate system of piping was introduced a few years ago to overcome the deficiencies in valves, fittings, methods of workmanship, and to insure greater reliability, and thus became a fad for a short time. This method has no further reason for application because manufacturers now meet the

demand with all materials for a first-class system. Reliability is better insured by careful design and superior workmanship, combined with the use of high-class materials and fittings and the judicious placing of cut-out and by-pass valves, all of which will result in a system superior to elaborate duplication.

**8.** Where several boilers of, say, 200 horsepower and upwards, are used, it will be found very convenient to place the *steam main*, or *header*, on or near the floor in the rear of the boiler; this brings all the large valves in accessible positions. The steam lines leading to engines are placed below the engine-room floor. This system is particularly applicable when horizontal engines are used.

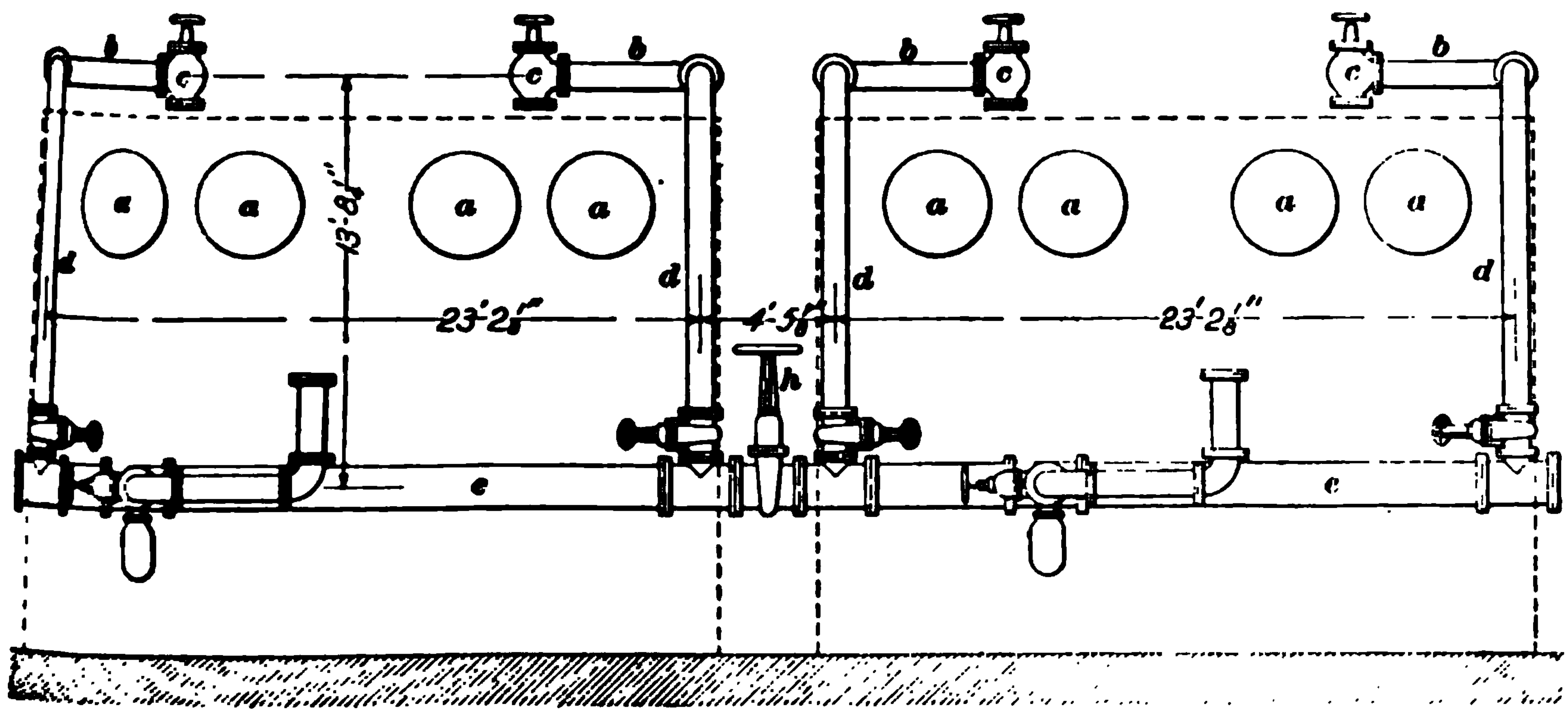


FIG. 3

The judicious use of long-radius bends, a most convenient arrangement of valves and location of live-steam header in accessible positions, and with steam connections to engines below engine-room floor, is shown in Figs. 1, 2, and 3. From the cross-connection between the 42-inch steam drums *a*, *a* of the water-tube boilers leads an 8-inch connection *b*, starting from an automatic stop- and check-valve *c*; the long-radius bend *b* is placed horizontally and connects with a similar bend *d* leading vertically in a downward direction to the live-steam header *e*. This arrangement gives great elasticity to a system of large piping, and the placing of the valves affords every convenience for ready manipulation.

In these figures, the main steam piping only is shown, the auxiliary piping for the boiler feedwater, heaters, etc. being omitted. Fig. 1 is a plan view, Fig. 2 an end view, and Fig. 3 a view showing the arrangement of the main steam pipes looking toward the rear of the boilers. The main steam pipes *f*, running from the header *c* to the high-pressure cylinders of the steam engines, are placed under the engine-room floor and a connection to the low-pressure cylinder is provided at *g* so that in case of emergency the low-pressure cylinder can be run with high-pressure steam. By examining the arrangement of valves between the boilers and engines, it is readily seen that it is possible to cut off any engine or boiler in case of accident and still run the plant with the remaining engines or boilers. The main steam header is divided into two sections by the large gate valve *h*, Figs. 1 and 3, so that one-half of the header can be entirely cut off from the other half.

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### PIPE BENDS

**9. Pipe bends** should be freely used to take up expansion strains and to reduce the number of joints where elbows would otherwise be required. Bends of short radius are undesirable, as they are so stiff that the object sought to be attained is not accomplished. Pipe bends of short radius with flanges can be used for elbows, but where it is intended to counteract the expansion strains on the system the radius of the bends should be liberal to allow the necessary elasticity. The radius of any bend should not be less than five diameters of the pipe, and a larger radius is preferable. The pipe should be carried completely through the flanges. The flanges should be refaced to bring them true with each other, and any protruding end of the pipe should be turned off to admit of the gasket having a full bearing. The best steam-fitting practice now uses these long double-swing bends. There is no special rule for the details of this method, which requires a knowledge of expansion of pipes when heated, and good judgment in placing the bends; the skill of the steam

fitter puts the strain on the pipes when cold, with the result that when the steam pressure is put on, the expansion removes the tension and no strain remains on the pipe except that due to the initial steam pressure. Slip expansion joints of any style have no place in a good job of steam fitting; they are exceedingly undesirable and will surely be a source of trouble and expense.

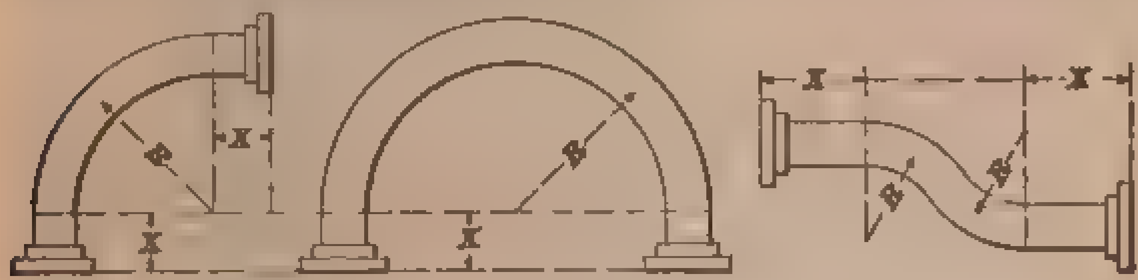



FIG. 4

**10. Dimensions of Pipe Bends.**—Table III, in connection with Fig. 4, shows the minimum radius of bends; all manufacturers prefer a longer radius than that indicated.

TABLE III

DIMENSIONS OF WROUGHT-IRON AND STEEL PIPE BENDS

| Diameter of Pipe Inches | Dimension X Inches | Minimum Radius R Inches | Diameter of Pipe Inches | Dimension X Inches | Minimum Radius R Inches |
|---|---|---|---|---|---|
| 2½ | 4 | 12½ | 7 | 8 | 35 |
| 3 | 4 | 15 | 8 | 9 | 40 |
| 3½ | 5 | 17½ | 10 | 12 | 50 |
| 4 | 5 | 20 | 12 | 14 | 60 |
| 4½ | 6 | 22½ | 15 | 16 | 75 |
| 5 | 6 | 25 | 16 | 20 | 80 |
| 6 | 7 | 30 | 18 | 22 | 90 |

## FLANGED JOINTS

**11.** In all pipe fitting for sizes of 3 inches and upwards it is most desirable to use **flange joints**; while the first cost is slightly in excess of the usual threaded fitting, the facilities offered for repairs and alterations, the freedom from leaks, and the general security of the job are sufficient to warrant the additional cost.

## TABLE IV

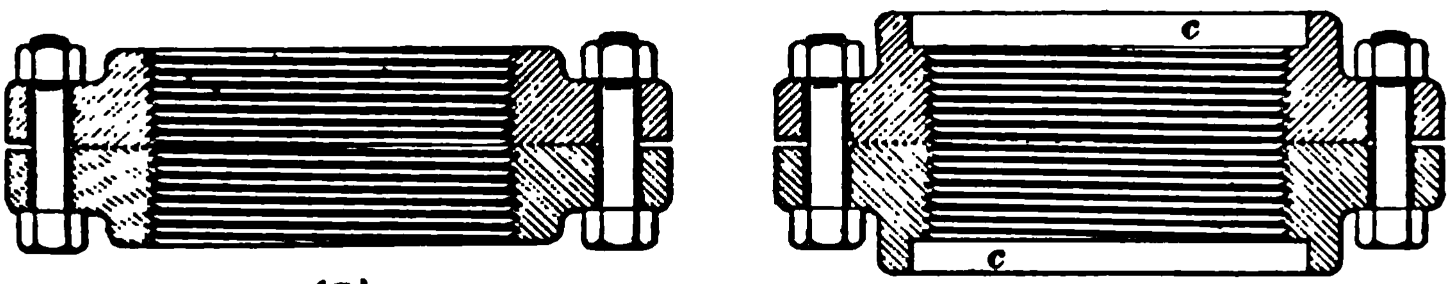
### DIMENSIONS OF EXTRA HEAVY PIPE FLANGES FOR 25 POUNDS WORKING PRESSURE

*Adopted by All the Leading Manufacturers*

| Size Inches | Diameter of Flanges Inches | Bolt Circle Inches | Number of Bolts | Size of Bolts | Length of Bolts Inches |
|---|---|---|---|---|---|
| 1 | 4½ | 3¼ | 4 | ½ | 2 |
| 1¼ | 5 | 3¾ | 4 | ½ | 2¼ |
| 1½ | 6 | 4½ | 4 | ⅝ | 2½ |
| 2 | 6½ | 5 | 4 | ⅝ | 2½ |
| 2½ | 7½ | 5⅞ | 4 | ¾ | 3 |
| 3 | 8¼ | 6⅝ | 8 | ⅝ | 3 |
| 3½ | 9 | 7¼ | 8 | ⅝ | 3¼ |
| 4 | 10 | 7⅞ | 8 | ¾ | 3½ |
| 4½ | 10½ | 8½ | 8 | ¾ | 3½ |
| 5 | 11 | 9¼ | 8 | ¾ | 3¾ |
| 6 | 12½ | 10⅝ | 12 | ¾ | 4 |
| 7 | 14 | 11⅞ | 12 | ⅞ | 4 |
| 8 | 15 | 13 | 12 | ⅞ | 4¼ |
| 9 | 16 | 14 | 12 | ⅞ | 4½ |
| 10 | 17½ | 15¼ | 16 | ⅞ | 4¾ |
| 12 | 20 | 17¾ | 16 | ⅞ | 5 |
| 14 | 22½ | 20 | 20 | ⅞ | 5¼ |
| 15 | 23½ | 21 | 20 | 1 | 5½ |
| 16 | 25 | 22½ | 20 | 1 | 5¾ |
| 18 | 27 | 24½ | 24 | 1 | 6 |
| 20 | 29½ | 26¾ | 24 | 1⅛ | 6¼ |
| 22 | 31½ | 28¾ | 28 | 1⅛ | 6½ |
| 24 | 34 | 31¼ | 28 | 1⅛ | 6¾ |

NOTE.—Flanges, flanged fittings, valves, etc. are drilled in multiples of four, so that fittings may be made to face in any quarter and holes straddle center line.

**12. Dimensions of Flange Fittings.**—A majority of the manufacturers of flanged fittings and valves have agreed on standard dimensions for the thickness and diameter of the flanges, the diameter of bolts and holes, the number and size of bolts, and the diameter of the bolt circle; unless especially ordered otherwise, flanges will be made according to this standard. This standard has also been adopted by a joint committee of the American Society of Mechanical Engineers, and the Master Fitters Association. This is referred to as the Manufacturers' Standard. Fig. 5 shows the shape of the standard flanges: (*a*) is used where the pipe is simply screwed into the flange and not calked, and (*b*) where the pipe is calked, a calking seam being provided at *c*. Table IV shows the standard dimensions of extra heavy flanges and flange bolts used for central-station piping where the pressure runs up as high as 250 pounds per square inch.




(a) (b)

FIG. 5

**13. Thickness of Flange Fittings.**—Flange fittings are generally made in three weights: the least for low pressure, such as exhaust or condenser connections; the second for standard pressures, up to 125 pounds; and the heaviest for high pressures, up to 250 pounds per square inch. The thickness in the three styles is shown in Table V.

These flanges are designed to have an unusually large factor of safety in order to cover possible defects in the metal or imperfections in casting. In all cases where using iron or gun-metal fittings, it is important to specify that the castings shall be absolutely sound and free from flaws, blow-holes, and shrinkage cracks.

**14. Methods of Making Flanged Joints.**—Several methods of making up flanged joints have been devised, tested, and abandoned; good practice has settled down to

TABLE V

THICKNESS OF PIPE FLANGES FOR VARIOUS PRESSURES

| Diameter of Pipe Inches | Low Pressure, 50 Pounds Inch | Medium Pressure, 125 Pounds Inches | Pressures Up to 250 Pounds Inches |
|---|---|---|---|
| 6 | $\frac{5}{8}$ | 1 | $1\frac{7}{16}$ |
| 8 | $\frac{3}{4}$ | $1\frac{1}{8}$ | $1\frac{5}{8}$ |
| 10 | $\frac{13}{16}$ | $1\frac{3}{16}$ | $1\frac{7}{8}$ |
| 12 | $\frac{13}{16}$ | $1\frac{1}{4}$ | 2 |
| 14 | $\frac{7}{8}$ | $1\frac{3}{8}$ | $2\frac{1}{8}$ |
| 16 | 1 | $1\frac{3}{8}$ | $2\frac{1}{4}$ |

two methods of making a good job of securing flanges to pipes. The first and most economical method is the threaded joint having the pipe thoroughly peened or hammered in the flange, making a secure and lasting fit; Fig. 6 shows this style of joint and the method of peening over the end of the pipe. The second and more expensive method is to have the flanges welded on the end of the pipe and then faced true in a lathe; this makes the most perfect and workmanlike joint in use at the present time.

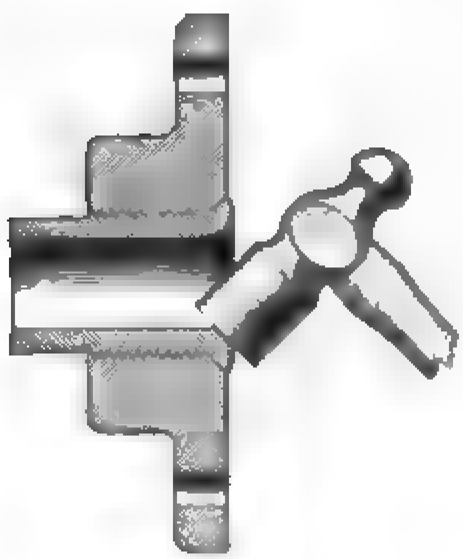
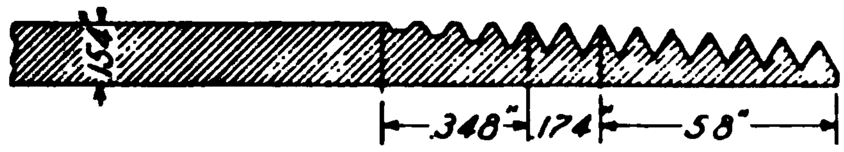


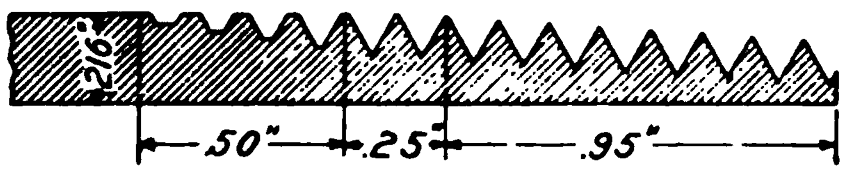
FIG. 6

Good practice for pressures up to 165 pounds is threaded flanges with the threads carefully cut, screwed on, and peened in the flange. A large number of tests have been made to determine the holding power of threads on piping, and results have shown that the strength of the threaded joint exceeds the strength of the flanged joint. Assuming that the shearing strength is one-half of the tensile strength of the metal, it is perfectly evident that the holding power of the threads is fully three times greater than the ultimate strength of the piping

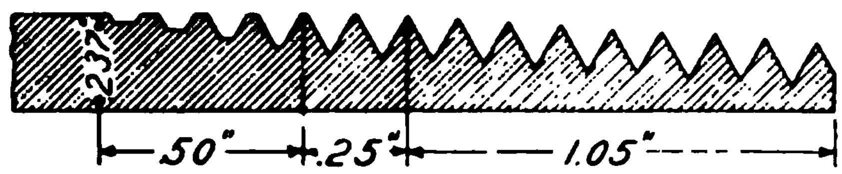
because of the number of threads that must be sheared before the joint gives way. It is desirable to make the threaded joints for flange fittings and high-pressure work longer than the standard, in order to reenforce the pipe by throwing a larger number of threads in contact, and thus guard against possible loosening by vibration.



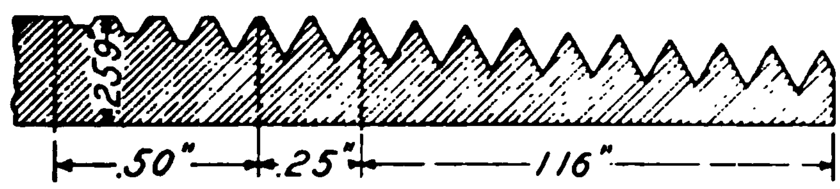

*Section through a Two-inch Pipe*



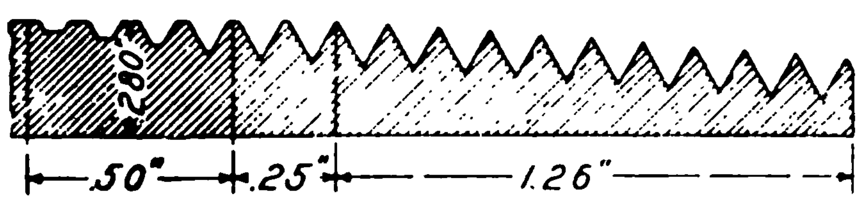

*Section through a Three-inch Pipe*




*Section through a Four-inch Pipe*




*Section through a Five-inch Pipe*




*Section through a Six-inch Pipe*

FIG. 7

**15. Pipe Threads.** It is important that the threads be perfectly cut, with first-quality tools in good order, to standard sizes. Imperfect and careless work in the cutting and fitting of threads should not be accepted. The repairs required to threaded joints because of leakage or failure are frequently caused by imperfect and unworkmanlike construction. For example, standard work on threaded 4-inch pipes requires eight perfect threads occupying 1.05 inches along the pipe; two that are perfect at the bottom and slightly flat on top, and four that are imperfect both at the top and bottom. The total length scored by the die on the pipe is approximately 1.8 inches. It is not uncommon to find only 1½ inches threaded on a 4-inch pipe and even on a 6-inch pipe, whereas the standard for the latter requires fully 2 inches. Fig. 7 shows the correct proportions of standard

threads on the several sizes of pipe commonly used. All piping that is used for service around an electric power station should be of standard size, standard thickness, standard thread, and round, straight, and perfect in every respect.

For ordinary pressures in sizes below 3 inches, the fittings should be heavy, beaded, gray-iron casting, tapped accurately to standard gauge; and for pressures in excess of 100 pounds, it is desirable that the fitting be extra heavy and made of gun metal. It is important that the piping should be screwed completely into the fitting or through the flange, to guard against all vibration and leakage, and to make the thread metal tight against oxidizing action by leaking steam or water. A properly erected system of pipe fitting should not show any indications of leakage under any conditions of expansion or contraction incident to daily service; where calking is required to stop leaks in threaded joints it is evident that the work is imperfect.

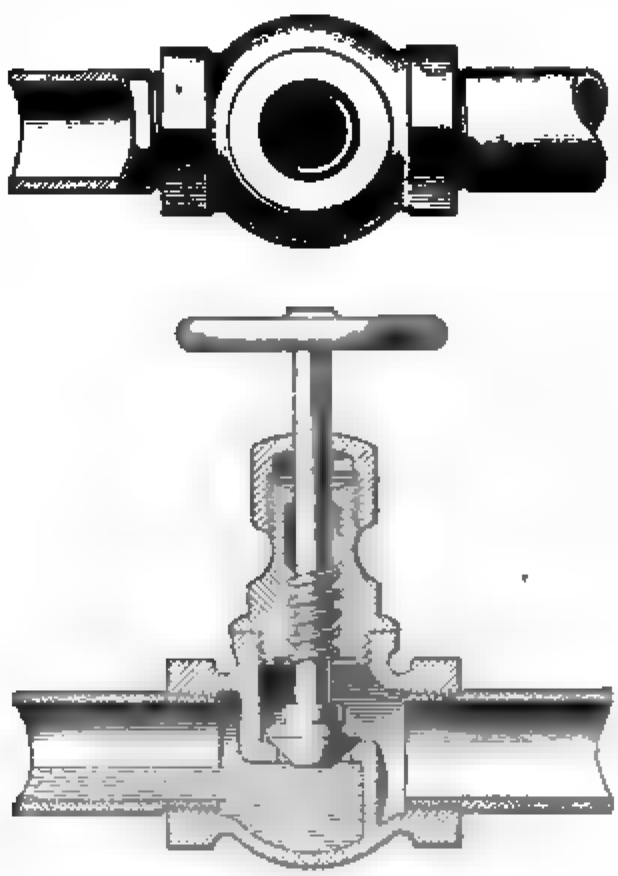


FIG. 8

## VALVES

**16.** A **valve** is required not only to withstand its working pressure, but also the strains of expansion and contraction, the weight of piping, and the cutting effect of the steam on the seat disk.

**17.** **Globe valves** are objectionable because of their clumsiness, resistance to passage of steam, and the water pockets that they bring about in the system of steam piping; Fig. 8 shows how they may allow the accumulation of water when placed on a horizontal or vertical position. The use

of globe valves should be avoided on all piping above 1¼ inches in diameter.

**18. Gate valves** are eminently desirable, and if frequently opened they will keep in good order and remain tight for many years; they are almost in universal use with the best standard of construction. They are manufactured for many lines of service, the principal being as follows: For low pressure not exceeding 50 pounds, and for exhaust

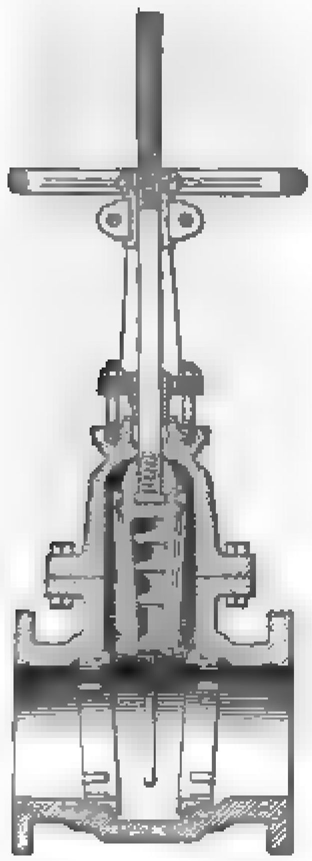


FIG. 9

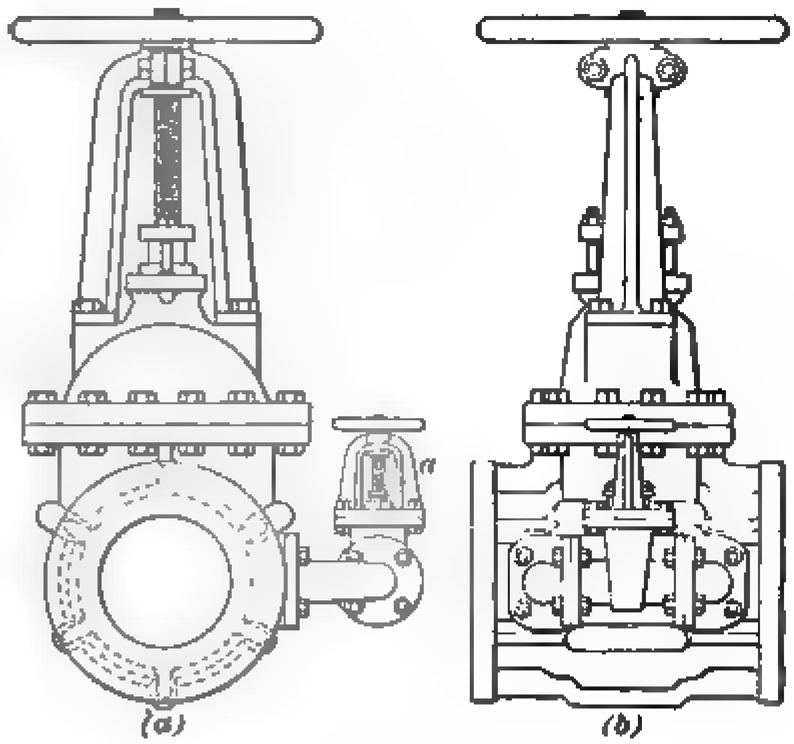



FIG. 10

and condenser service; for pressure not exceeding 125 pounds; for medium pressure not exceeding 150 pounds; and for extra heavy pressures not exceeding 250 pounds. Standard valves from 4 inches to 8 inches should withstand a hydrostatic pressure of 600 pounds, and from 10 inches to 16 inches a hydrostatic pressure of 500 pounds without showing any defects. Valves for medium and extra heavy pressures should withstand from 1,200 to 1,500 pounds hydrostatic pressure.

For valves of 6 inches and upwards on steam lines, it is desirable to use the outside screw yoke, with stationary wheel and rising spindle, as shown in Fig. 9. The advantages of this type are that the extension of the stem shows the position of the gate; also, the screw can always be properly lubricated and does not come in contact with the steam.

By-passes are desirable on or around all valves, for live steam, of 6 inches and upwards. The by-pass permits of the easy equalizing of pressure on both sides, before opening the main valve. Fig. 10 shows a gate valve provided with a small by-pass valve *a*. By first opening the small valve the pressure on the two sides of the gate valve is equalized, thus making the valve easy to open.

---

## RECEIVERS

**19. Reduced Pipe Diameters With Receivers.** The best-designed systems now use sizes of live-steam piping from 5 to 15 per cent. smaller than that called for by the engine builders for throttle-valve connections. These pipes deliver the steam into wrought-iron or steel **receivers**, which also act as separators, separating moisture from the steam. These receivers should have a capacity of from three to four times that of the high-pressure cylinder, and should be placed as close as possible to the cylinder.

In a system thus arranged for live steam, the action is as follows: At each stroke of the piston the engine obtains from the receiver the necessary volume of steam, the withdrawal of which for a fraction of a second reduces the pressure in the receiver. The boiler pressure behind the live steam in the pipe rushes new steam to the receiver at high velocity, thus restoring instantly the volume and pressure required for the next stroke of the engine. This process follows continuously, and a higher velocity in the flow of steam in the smaller pipes and larger volume for the engine to draw from, as well as separation of moisture, is thus obtained.

This arrangement also provides a cushion near the engine, which takes the reaction caused by the quick cut-off in the steam chest and prevents vibration from being transmitted through the system of piping. This plan of reduced diameters of live-steam pipe, combined with receivers, tends to produce a steady and rapid flow of steam in the direction of the engine. A system so arranged need not incur a loss of more than 1 or 2 pounds between boiler and engines, unless the engines are a long distance from the boilers, and even then the loss need not exceed 3 or 4 pounds for 400 to 500 feet transmission. The initial cost of the receiver system of piping will be considerably less than that using larger diameters of pipe without receivers.

---

### EXHAUST PIPING

**20.** Most of the details previously described apply equally well to the design and fitting of **exhaust-pipe systems.** On account of the reduced pressure it is not necessary to use weights of pipe heavier than standard, due provision being allowed for expansion and contraction. Special care should be observed that the diameters of pipes are liberal, the bends of easy radius, and gate valves employed to the end that no back pressure be caused. When piping exhaust systems to condensers, the greatest care is necessary to secure air-tight work, as emphasized in connection with condensers. The placing of non-conducting covering on exhaust systems is usually done where the heat is desired for the feedwater, also to insure a lower temperature in the station. It is not necessary for this covering to be as thick as for live-steam systems.

---

### STEAM JOINTS

**21.** The faces of flanges have been formed in many ways with the object of preventing the gasket from blowing out. The tongue-and-groove, raised faces, male-and-female ends have all been thoroughly tried, and cost somewhat in excess of a straight face and corrugated joint.

The straight-face joint slightly corrugated, if properly put together with a good gasket, will stand a test of 1,000 pounds without blowing out.

**22. Gaskets.**—Many styles of gaskets have been experimented with, but the most satisfactory thus far found is the corrugated copper gasket placed within the bolt circle and well pulled up; this makes a joint that is very durable. Gaskets containing rubber, asbestos, or alloys of soft metal require constant attention, and with superheated steam are quickly destroyed.

It is very essential that all the miscellaneous fittings, such as gauge-cocks, gauge-glasses, blow-off cocks, water-supply fittings, trap connections, lubricators, etc., should be extra heavy. While these represent very small items of cost in comparison to the total cost of the job of piping, a blow-out in any one will be the cause of a great deal of inconvenience and will sometimes result in far more expense than would have been the first cost of the kind of fittings suggested.

## PIPE SUPPORTS

**23.** It is essential that the whole system of piping be supported in such a manner that there shall be perfect freedom for expansion and contraction, without undue strain on any section. The correct location of supports cannot be specified in advance and becomes a matter of good judgment as the system is erected. Several suitable appliances are illustrated in Figs. 11 and 12. Where large pipe systems are laid near the floor, it is desirable to build brick piers capped with iron plates, surmounted by iron rollers, say, 1 or 2 inches in diameter, on which the pipe rests.

**24. Expansion of Wrought-Iron Pipes.**—The amount by which a wrought-iron pipe will expand when heated can be determined by the following rule:

**Rule.**—*Multiply the length of pipe, in inches, by the number of degrees to which it is heated, and divide by 150,000; this gives the expansion, in inches.*

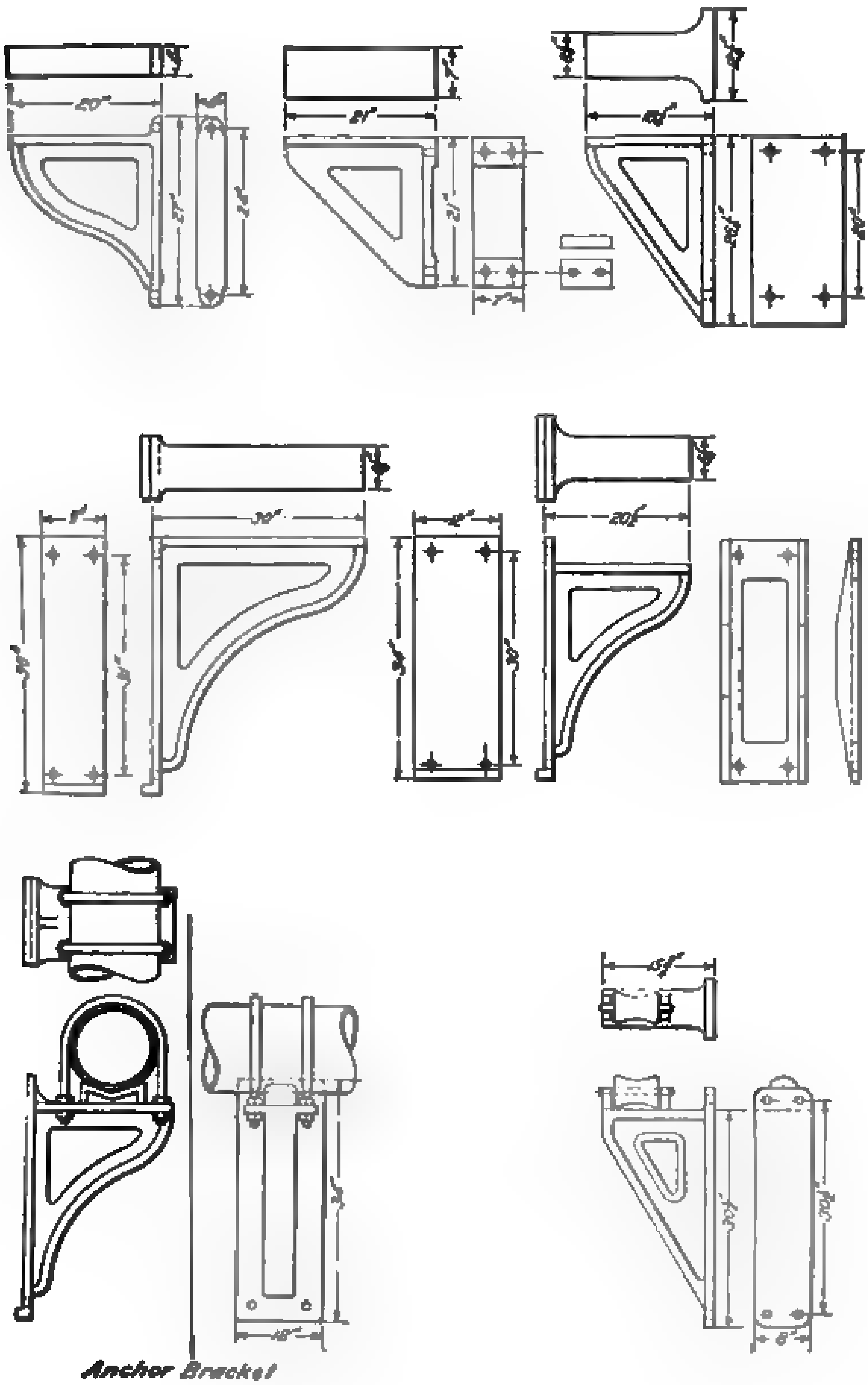



FIG. 11

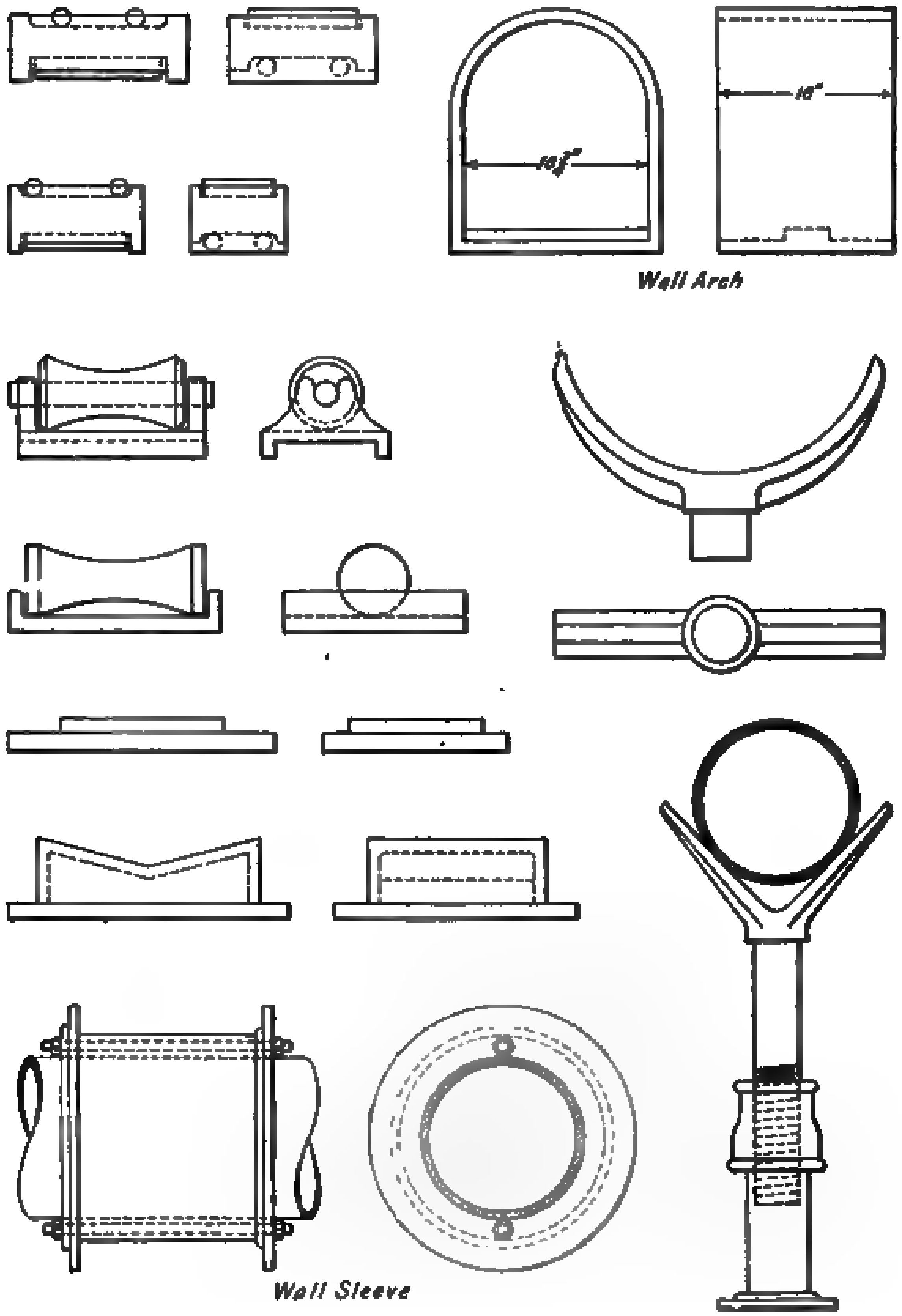



FIG. 12

Cast-iron pipe expands $\frac{1}{162000}$ of its length for each degree Fahrenheit it is subjected to under ordinary conditions; wrought-iron pipe $\frac{1}{150000}$. A 2-inch pipe when heated to a temperature of 338° F. (temperature of steam at 100 pounds pressure) exerts an expansive force of 25 tons.

---

### QUALITY OF PIPING AND FITTINGS

**25.** The standard grades of wrought-iron pipe are known as *butt-welded*, *lap-welded*, *extra strong*, and *double extra strong*. Table VI shows the standard dimensions of wrought-iron piping from $\frac{1}{8}$ inch to 12 inches diameter, inclusive. Standard wrought-iron pipe lap-welded is always tested at the mills to a pressure of 500 pounds per square inch, by hydrostatic pressure. Commercial piping in sizes of 12 inches and under with perfectly welded joints has been tested up to 1,500 pounds per square inch without bursting; 8-inch and 10-inch piping taken from stock at random has been tested to 2,000 pounds per square inch; 16-inch pipe to 800, and 24-inch pipe to 600 pounds without rupture or fracture. It would appear that there is, therefore, no reason why, for diameters less than 15 inches and pressures up to 200 pounds per square inch, piping heavier than standard should be used for the live-steam system in an electric power station.

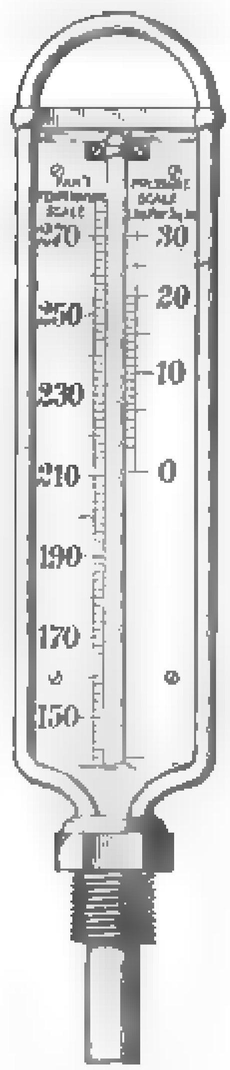



FIG. 13

Wrought-steel piping has now become so reliable and is so generally used, especially in the larger sizes, that it is preferable to wrought-iron pipe. For expansion bends, it is equally well made and reliable, and copper bends need only be used for very heavy work. All pipes, valves, fittings, and materials used on a first-class job are now readily obtained to withstand the required working pressure of 200 pounds per square inch. Any modern job of steam fitting necessarily requires good design, good material, and skilful workmanship.

# TABLE VI

## STANDARD DIMENSIONS FOR WROUGHT-IRON AND STEEL STEAM, GAS, AND WATER PIPE

| Diameter | | | Nominal Thickness Inches | Circumference | | Transverse Areas | | | Length of Pipe per Square Foot of | | Length of Pipe Containing 1 Cubic Foot Feet | Nominal Weight per Foot Pounds | Number of Threads per Inch of Screw |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nominal Internal Inches | Actual External Inches | Approximate Internal Diameter Inches | | External Inches | Internal Inches | External Square Inches | Internal Square Inches | Metal Square Inches | External Surface Feet | Internal Surface Feet | | | |
| 1/8 | .405 | .270 | .068 | 1.272 | .848 | .129 | .0573 | .0717 | 9.440 | 14.15 | 2,513.0 | .241 | 27 |
| 1/4 | .54 | .364 | .088 | 1.696 | 1.144 | .229 | .1041 | .1249 | 7.075 | 10.49 | 1,383.3 | .420 | 18 |
| 3/8 | .675 | .494 | .091 | 2.121 | 1.552 | .358 | .1917 | .1663 | 5.657 | 7.73 | 751.2 | .559 | 18 |
| 1/2 | .84 | .623 | .109 | 2.639 | 1.957 | .554 | .3048 | .2492 | 4.547 | 6.13 | 472.4 | .837 | 14 |
| 3/4 | 1.05 | .824 | .113 | 3.299 | 2.589 | .866 | .5333 | .3327 | 3.637 | 4.635 | 270.0 | 1.115 | 14 |
| 1 | 1.315 | 1.048 | .134 | 4.131 | 3.292 | 1.358 | .8626 | .4954 | 2.904 | 3.645 | 166.9 | 1.668 | 11 1/2 |
| 1 1/4 | 1.66 | 1.380 | .140 | 5.215 | 4.335 | 2.164 | 1.496 | .6680 | 2.301 | 2.768 | 96.25 | 2.244 | 11 1/2 |
| 1 1/2 | 1.9 | 1.611 | .145 | 5.969 | 5.061 | 2.835 | 2.038 | .7970 | 2.010 | 2.371 | 70.66 | 2.678 | 11 1/2 |
| 2 | 2.375 | 2.067 | .154 | 7.461 | 6.494 | 4.430 | 3.356 | 1.074 | 1.608 | 1.848 | 42.91 | 3.609 | 8 |
| 2 1/2 | 2.875 | 2.468 | .204 | 9.032 | 7.753 | 6.492 | 4.784 | 1.708 | 1.328 | 1.547 | 30.10 | 5.739 | 8 |
| 3 | 3.50 | 3.067 | .217 | 10.996 | 9.636 | 9.621 | 7.388 | 2.243 | 1.091 | 1.245 | 19.50 | 7.536 | 8 |
| 3 1/2 | 4.0 | 3.548 | .226 | 12.566 | 11.146 | 12.566 | 9.887 | 2.679 | .955 | 1.077 | 14.57 | 9.001 | 8 |
| 4 | 4.5 | 4.026 | .237 | 14.137 | 12.648 | 15.904 | 12.730 | 3.174 | .849 | .949 | 11.31 | 10.665 | 8 |
| 4 1/2 | 5.0 | 4.508 | .246 | 15.708 | 14.162 | 19.635 | 15.961 | 3.674 | .764 | .848 | 9.02 | 12.490 | 8 |
| 5 | 5.563 | 5.045 | .259 | 17.477 | 15.849 | 24.306 | 19.990 | 4.316 | .687 | .757 | 7.20 | 14.502 | 8 |
| 6 | 6.625 | 6.065 | .280 | 20.813 | 19.054 | 34.472 | 28.888 | 5.584 | .577 | .630 | 4.98 | 18.762 | 8 |
| 7 | 7.625 | 7.023 | .301 | 23.955 | 22.063 | 45.664 | 38.738 | 6.926 | .501 | .544 | 3.72 | 23.271 | 8 |
| 8 | 8.625 | 7.982 | .322 | 27.096 | 25.076 | 58.426 | 50.040 | 8.386 | .443 | .478 | 2.88 | 28.177 | 8 |
| 9 | 9.625 | 8.937 | .344 | 30.238 | 28.076 | 72.760 | 62.730 | 10.030 | .397 | .427 | 2.29 | 33.701 | 8 |
| 10 | 10.75 | 10.019 | .366 | 33.772 | 31.477 | 90.763 | 78.839 | 11.924 | .355 | .382 | 1.82 | 40.065 | 8 |
| 11 | 11 75 | 11. | | 36.914 | 34.558 | 108.434 | 95.033 | 13.401 | .325 | .347 | 1.51 | 45.028 | 8 |
| 12 | 12.75 | 12. | | 40.055 | 37.700 | 127.677 | 113.098 | 14.579 | .299 | .319 | 1.27 | 48.985 | 8 |

**26. Piping for Feedwater System.**—Experience has shown that hot feedwater corrodes wrought-iron pipe quite rapidly, due to the amount of impurities in the water. It is therefore most desirable to use extra thick pipe for this purpose, but it is far better to use brass pipe than wrought-iron pipe if the expense is not too great. The brass pipe is not subject to corrosion, and even the extra thick wrought-iron piping will require replacing within a few years.

**27.** In order to test the temperature of feedwater, it is desirable to locate pockets for testing thermometers at

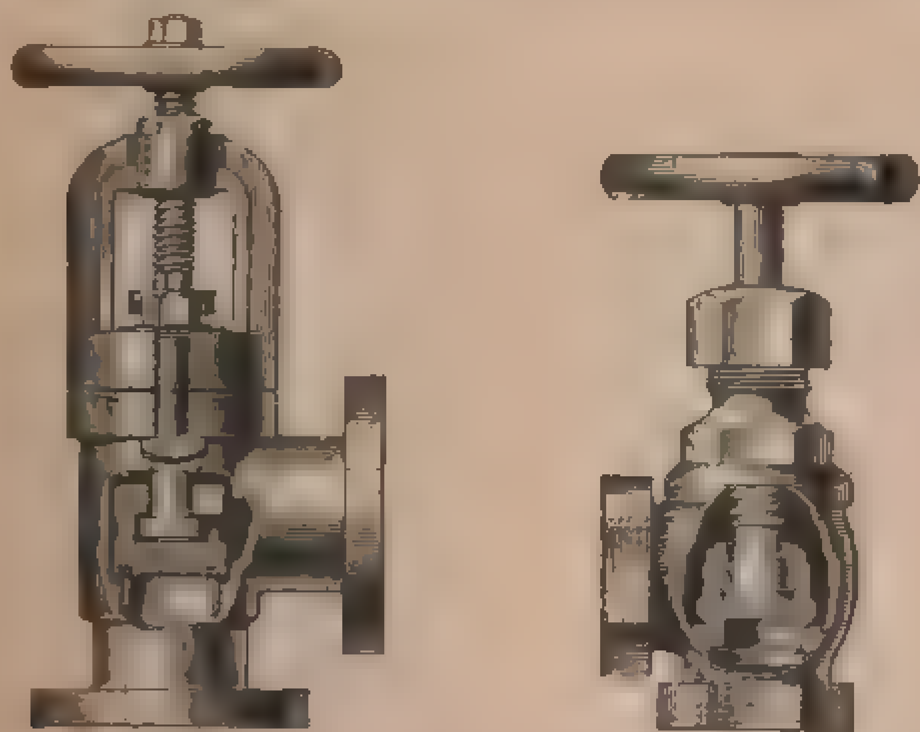


FIG. 14

suitable points; Fig. 13 shows a thermometer provided with a pocket for screwing into the pipe.

The feedwater-pipe connections to every boiler should be duplicated or so interconnected that the boiler can be supplied at either of two feeding-in points, or from either of two directions, to the end that the supply of feedwater shall be sure beyond all question of failure. This is particularly important if brass feedwater piping is not used. The valves set in the feedwater pipe leading to each boiler should consist of a flanged gate valve with companion flanges, a flanged check-valve, and a second flanged gate valve. For double-deck

water-tube boilers, it is also desirable to have a duplicate steam pressure gauge at about 7 feet above floor level.

**28. Blow-Off Valves.**—The ordinary **blow-off valve** usually supplied with boilers is of little or no practical value in power-station service. A valve should be used that will withstand the cutting effects of scale and sediment. This is a point that should be unusually well guarded, otherwise continual repairs will be necessary because of leaky blow-off valves. Fig. 14 shows two types of blow-off valves of satisfactory design.

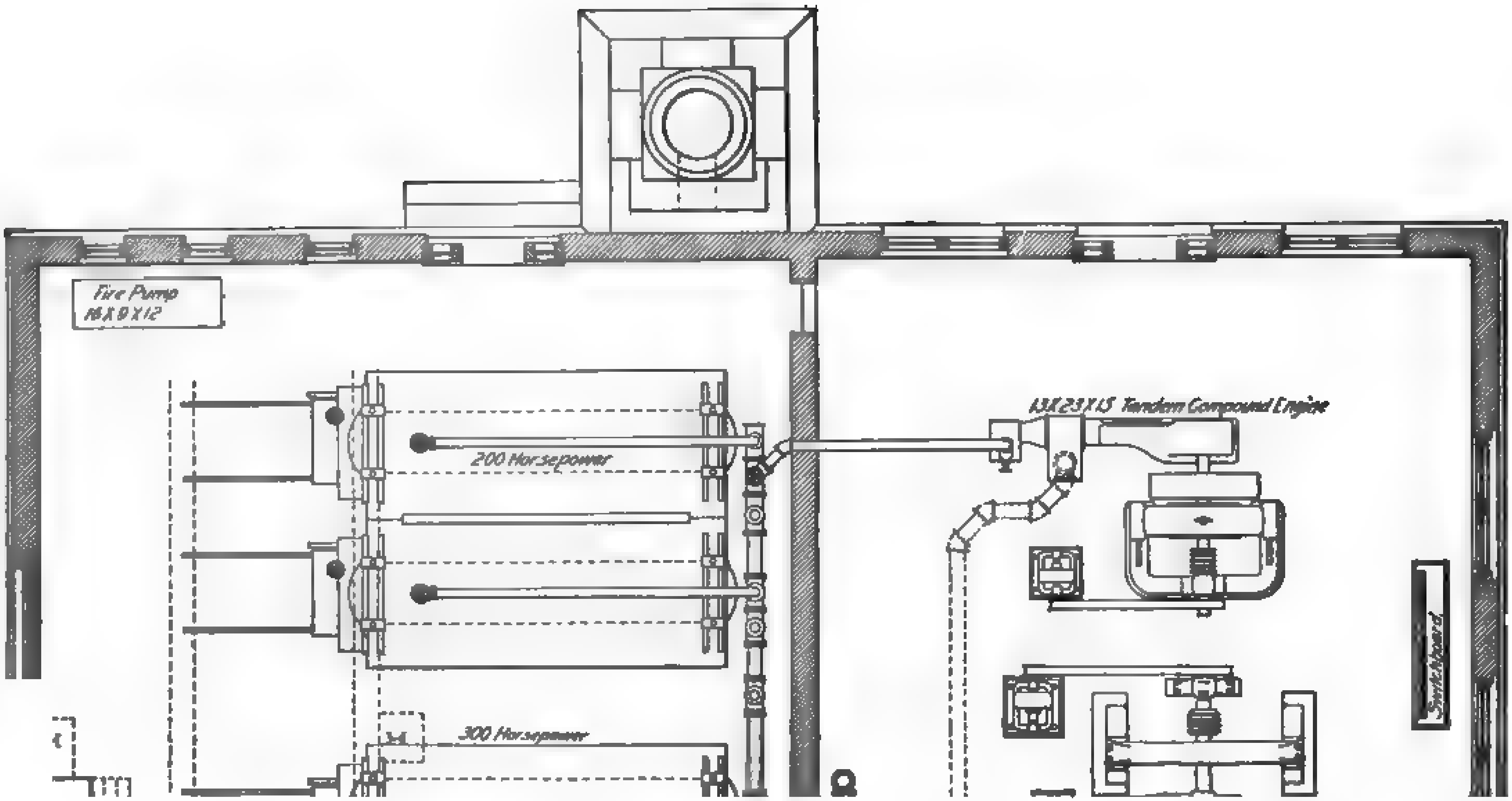
---

## PIPE COVERING

**29.** The importance of protecting steam pipes from loss by radiation is so generally acknowledged that we shall only touch on the salient points to emphasize the reasons for loss if not covered, and the importance of the saving effected when the work is properly done.

Between two bodies near each other and at different temperatures, there exists a tendency to temperature equalization by radiation, conduction, and convection. The very great difference in temperature between the surrounding atmosphere and a pipe containing steam or water at a high temperature is a cause for rapid radiation from the surface of the pipe to the atmosphere. This rapid radiation is a direct loss of the heat units derived from the fuel and stored up in the steam. To prevent this loss, it is essential that all live-steam pipes, and also those containing hot water for boiler feed, should be protected by a covering that is a non-conductor of heat. The value of a pipe covering will be represented by the saving in the money expended for fuel that would otherwise be wasted.

The following items must be considered in order to properly determine the economic value of a pipe covering: (*a*) The cost of the covering; (*b*) the cost of coal required to supply the loss of heat if the pipes are not covered; (*c*) the extra capital required to be invested in boilers to make up for the loss and the interest on the investment; (*d*) the guaranteed life of the covering.


Fire Pump
16 X 9 X 12
200 Horsepower
300 Horsepower
13 X 23 X 15 Tandem Compound Engine
Switchboard

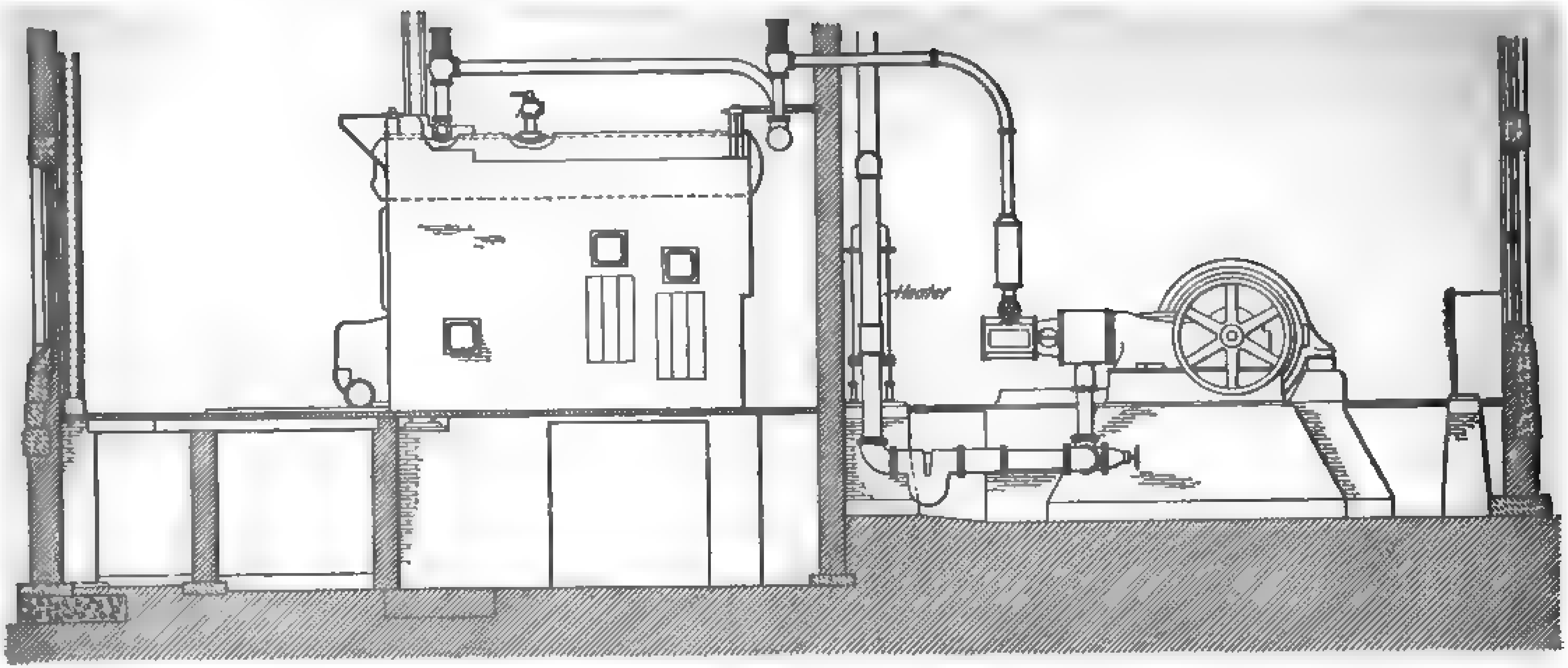



Fig. 15

**30.** The loss by radiation and the saving effected by a good covering may be illustrated by the following examples:

EXAMPLE 1.—If a bare steam pipe gives off 2 heat units per hour per square foot of external surface per degree difference in temperature, and only .4 unit when covered with a high-class covering, what will be the difference in weight of condensation per hour in a 12-inch steam main 120 feet long carrying steam at 100 pounds gauge pressure and exposed to an external temperature of 20° F.?

SOLUTION.—The external surface of a pipe of these dimensions is about 400 sq. ft.; the temperature of steam at 100 lb. pressure is 337.8°. Therefore $(337.8 - 20) \times 2 \times 400 = 254,240$ = the heat loss for the bare pipe. Similarly $(337.8 - 20) \times .4 \times 400 = 50,848$ = the heat loss when the pipe is covered; then, $254,240 - 50,848 = 203,392$ = saving in heat units (B. T. U.) per hour by covering the pipe.

We also find from the steam table that the latent heat of evaporation for steam at 100 lb. pressure is 875.4, which means that 1 lb. of steam is condensed for 875.4 heat units that are given off. Then the difference in weight of condensation per hour when the pipe is covered is $203,392 \div 875.4 = 232$ lb. Ans.

EXAMPLE 2.—If 11,000 heat units is utilized per pound of coal in making steam, how many pounds of coal will be saved per hour by covering the pipe?

SOLUTION.—We have found that covering the pipe effects a saving of 203,392 heat units, and if 1 lb. of coal represents 11,000 heat units imparted to the steam, the coal saved per hour will be $203,392 \div 11,000 = 18.49$ lb. Ans.

The saving per 100 square feet of surface in 1 year under these conditions will vary according to the quality and thickness of the covering, and the quality and cost of coal, and can be readily estimated for any given condition.

**31.** The decision as to choice of material must regard other conditions as well as that of conductivity. As some pipe coverings are good non-conductors of heat but are not fireproof, the question of the ability of a pipe covering to withstand the action of heat for a prolonged period without being destroyed, or carbonized, or rendered less efficient is of vital importance.

Tests have been made in this direction for long periods, and results show that the choice of covering should be confined to magnesia, first-quality asbestos, magnesia asbestos,

ground and compressed cork, and other coverings of similar composite character. Such coverings as wool, hair felt, wool felt, sawdust, or paper pulp are liable to become charred and carbonized by heat from the pipe, and finally ignited; such coverings are not worth the money and labor expended on them. Sectional covering is most desirable, as it can be removed when repairs are needed, and replaced with but slight waste of material, and only the cost of labor.

For a specified result of minimum radiation, different grades and qualities of covering will require to be of different thicknesses, and if first cost and real utility are to be compared under fair conditions, the specification should require a guarantee that the covering around a pipe carrying steam at a given pressure and temperature shall not show a loss of British thermal units per square foot of pipe surface per minute exceeding a percentage to be determined according to the quality and thickness of the covering selected.

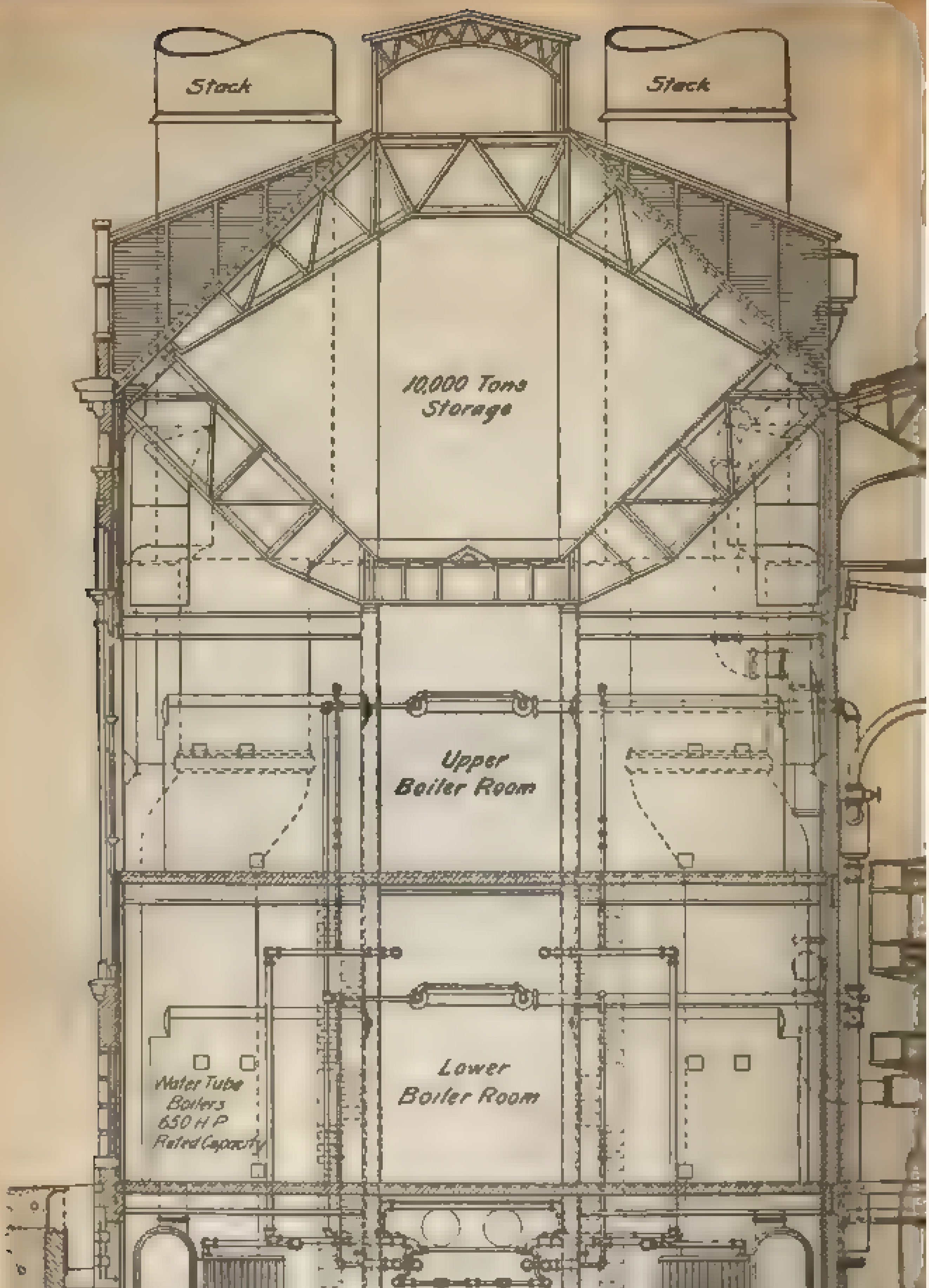
## EXAMPLES OF STEAM PIPING AND GENERAL ARRANGEMENT OF PLANT

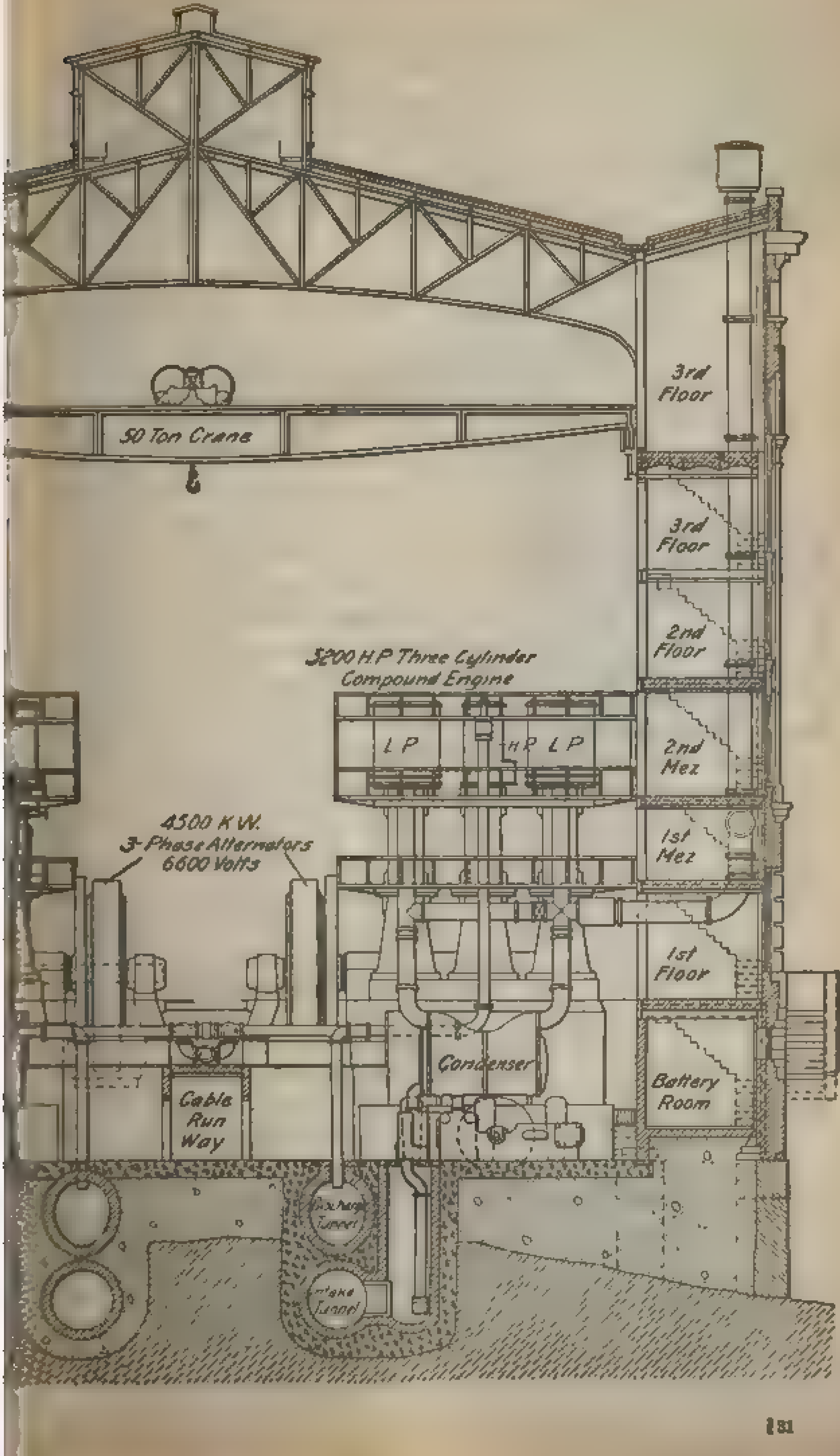
### MEDIUM-SIZE PLANTS

**32.** In order to illustrate the general arrangement of steam plants, particularly with reference to the arrangement of steam boilers, steam piping, and engines, a few typical cases are given.

Fig. 15 shows the arrangement of a plant of comparatively small output in which the steam piping is of about the simplest possible character. In this plant three Babcock and Wilcox water-tube boilers supply steam to two tandem compound engines direct-coupled to polyphase alternators. The total rated boiler capacity is 500 horsepower. Condensers are not used and the steam exhausts into the atmosphere after passing through the feedwater heater.

**33.** Fig. 16 shows a larger plant with cross-compound condensing engines. This plant has 900 rated horsepower boiler capacity and 750 kilowatts in generator capacity. The


Stack
Stack
10,000 Tons Storage
Upper Boiler Room
Lower Boiler Room
Water Tube Boilers 650 H P Rated Capacity


3rd Floor
50 Ton Crane
3rd Floor
2nd Floor
3200 H.P Three Cylinder Compound Engine
L P
H P
L P
2nd Mez
4500 K.W. 3-Phase Alternators 6600 Volts
1st Mez
1st Floor
Condenser
Cable Run Way
Battery Room

exhaust steam is condensed by means of jet condensers and the feedwater heated by means of a Cochrane feedwater heater and purifier. The condensers and pumps are placed in a pit somewhat below the engine-room floor line. Fuel is supplied to the boiler by means of Roney stokers, which are fed from a coal bin, as indicated in the figure.

**34.** Fig. 17 shows a plan of a traction plant in which alternating current is generated for transmission to distant parts of the line. The generating equipment consists of two 900-horsepower cross-compound engines direct-connected to 600-kilowatt alternators. The direct current required for operating the cars is obtained from substations by stepping-down the high-tension alternating current and passing it through rotary converters. The two rotary converters shown in the station are for supplying the near-by portions of the road with direct current. If a large proportion of the output were to be used as direct current, it might be advisable to install double-current generators instead of plain alternators and thus dispense with the rotary converters in the power station. The exhaust steam from the engines is condensed by means of a siphon or barometric condenser, and in order to maintain a good vacuum, a dry-air pump (i. e., an air pump that pumps out vapor and air only and not a mixture of these with water) is attached to the condenser chamber. The pumps used for handling the feedwater and injection water are located as shown in the figure, together with the usual fire-pump for furnishing a water pressure for fire-protection. The fields of the alternators are excited by means of two independent exciters driven by small direct-connected steam engines.

### LARGE PLANTS

**35.** As examples of the very large plants that are now becoming common in large cities, we will take the Waterside station of the New York Edison Company, and the power station of the Manhattan Elevated Railway, New York. A cross-section of the Waterside station is shown in Fig. 18, and a skeleton plan, showing the arrangement of boilers,

engines, and steam piping, in Fig. 19. There are two tiers of boilers with twenty-eight boilers in each, fifty-six altogether.

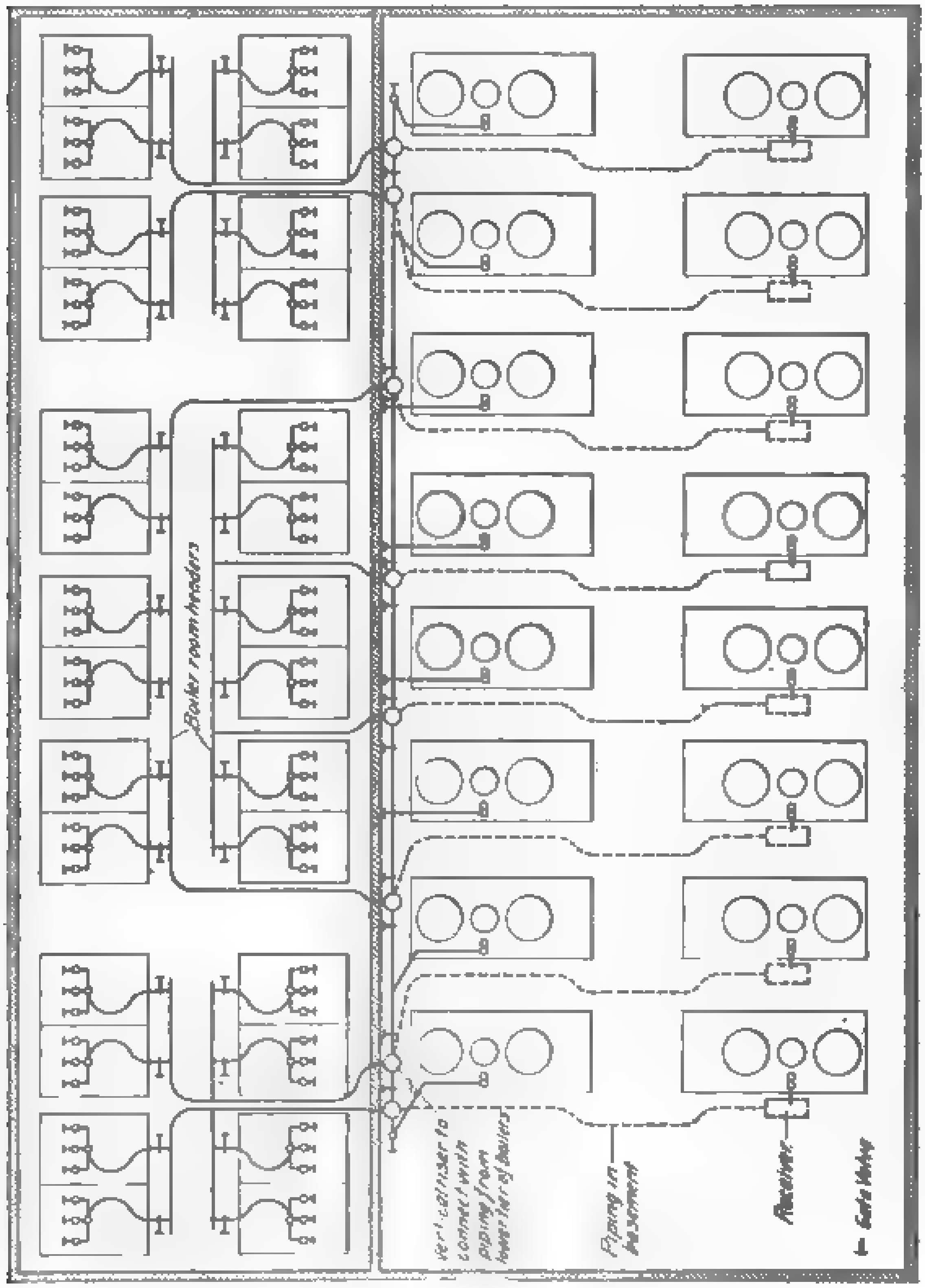



FIG. 19

These boilers supply sixteen vertical engines, which work most economically at about 5,200 horsepower each or a total output of 83,200 horsepower; the station is, however, capable

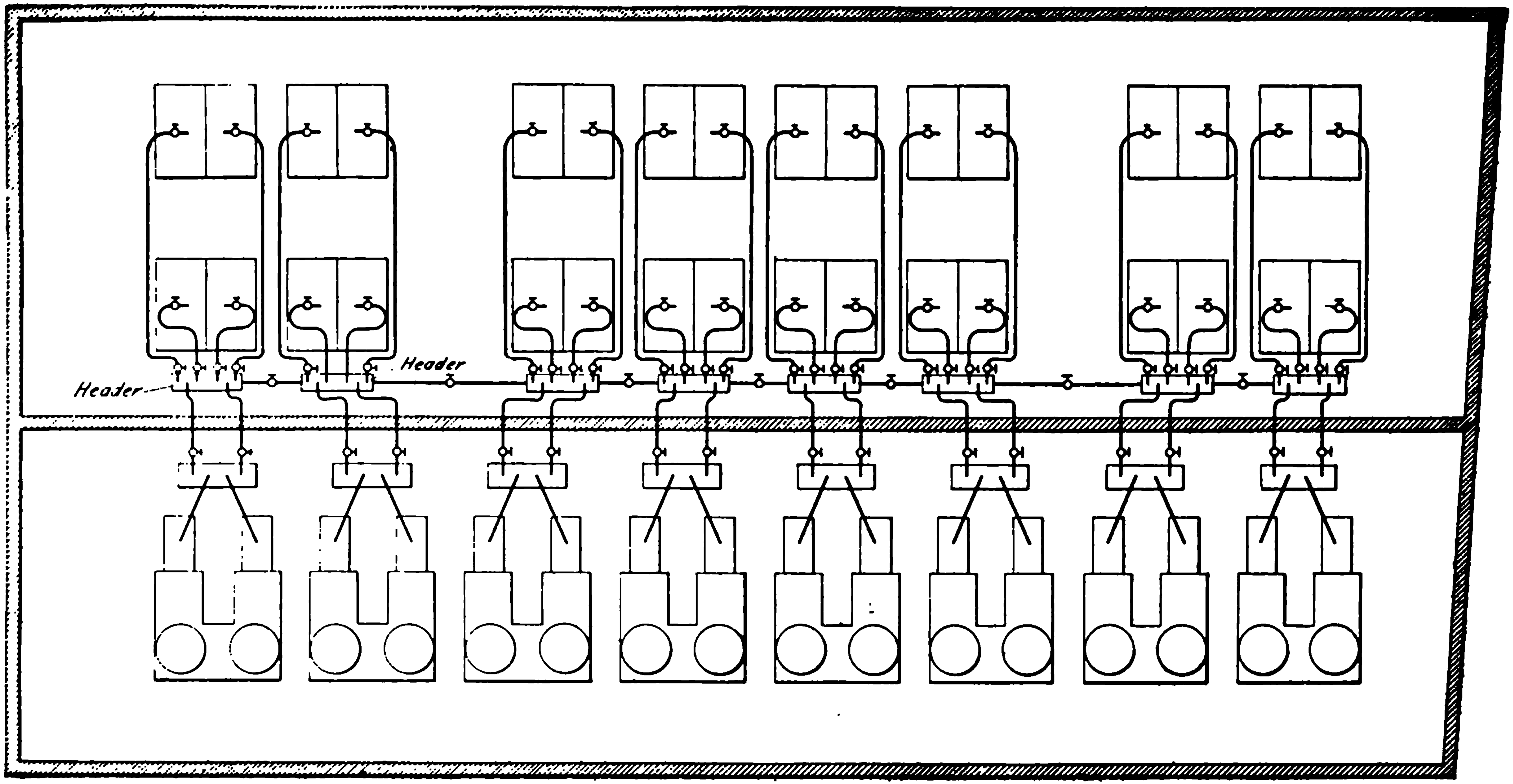
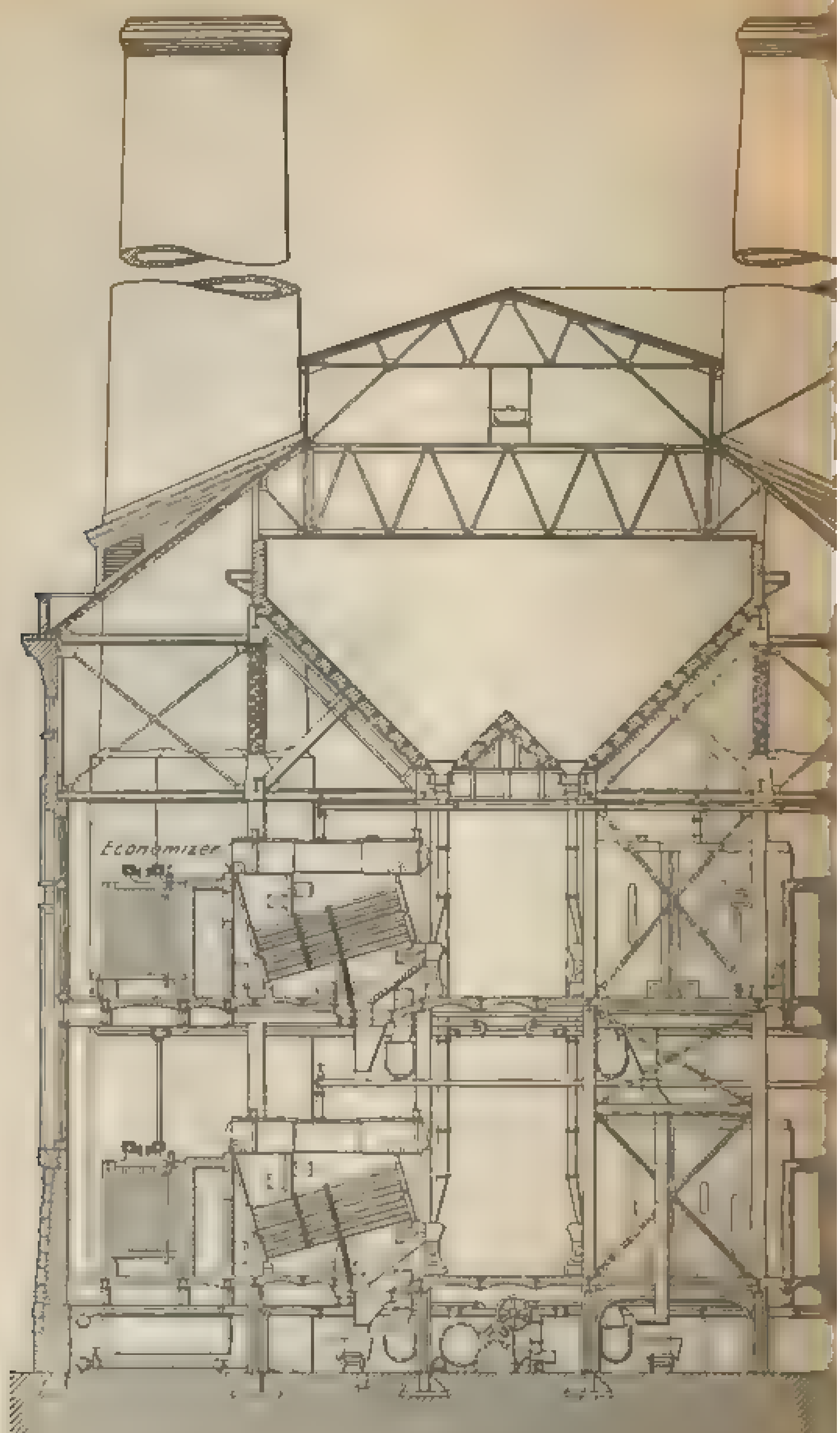



FIG. 21


Economizer

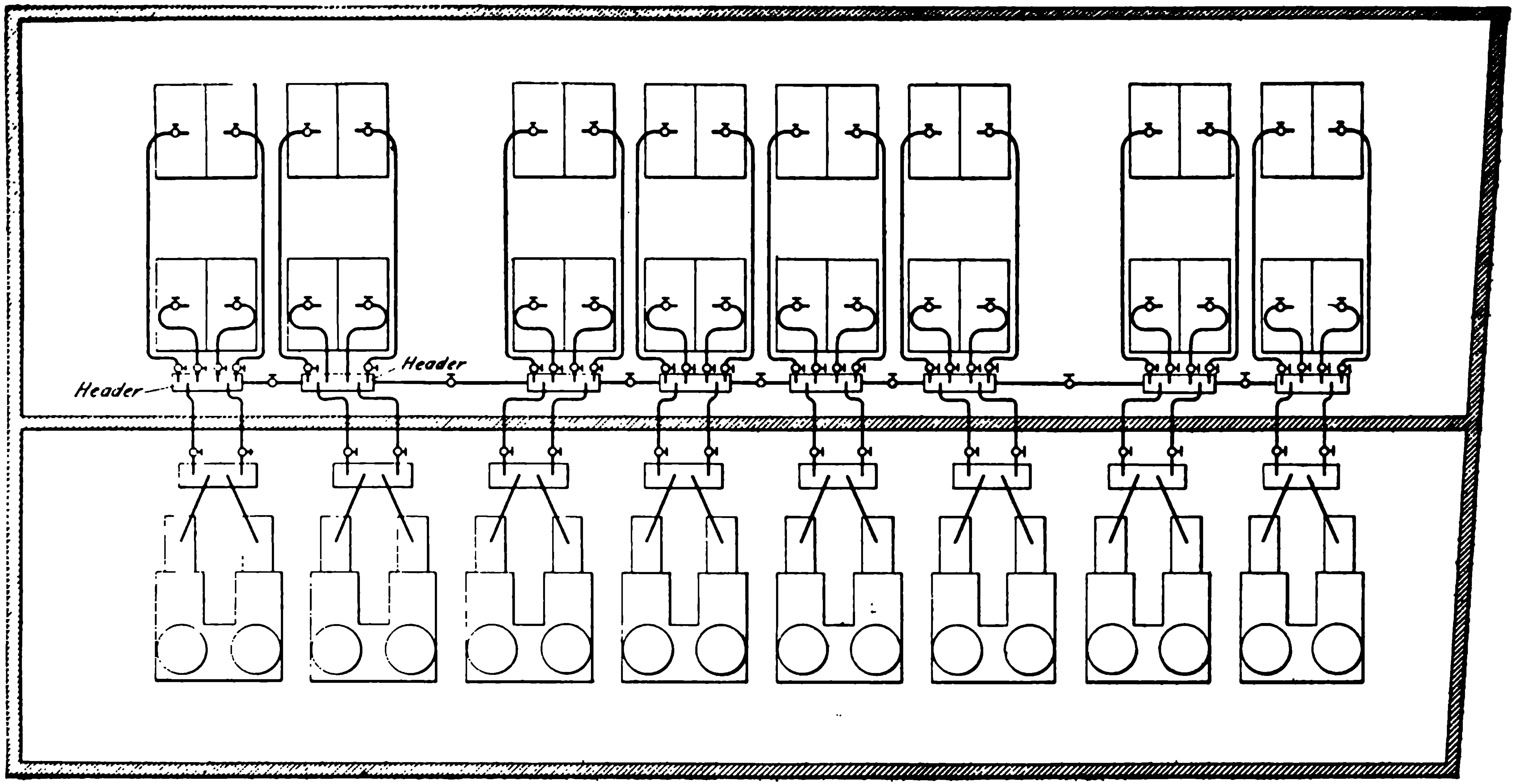



FIG. 21

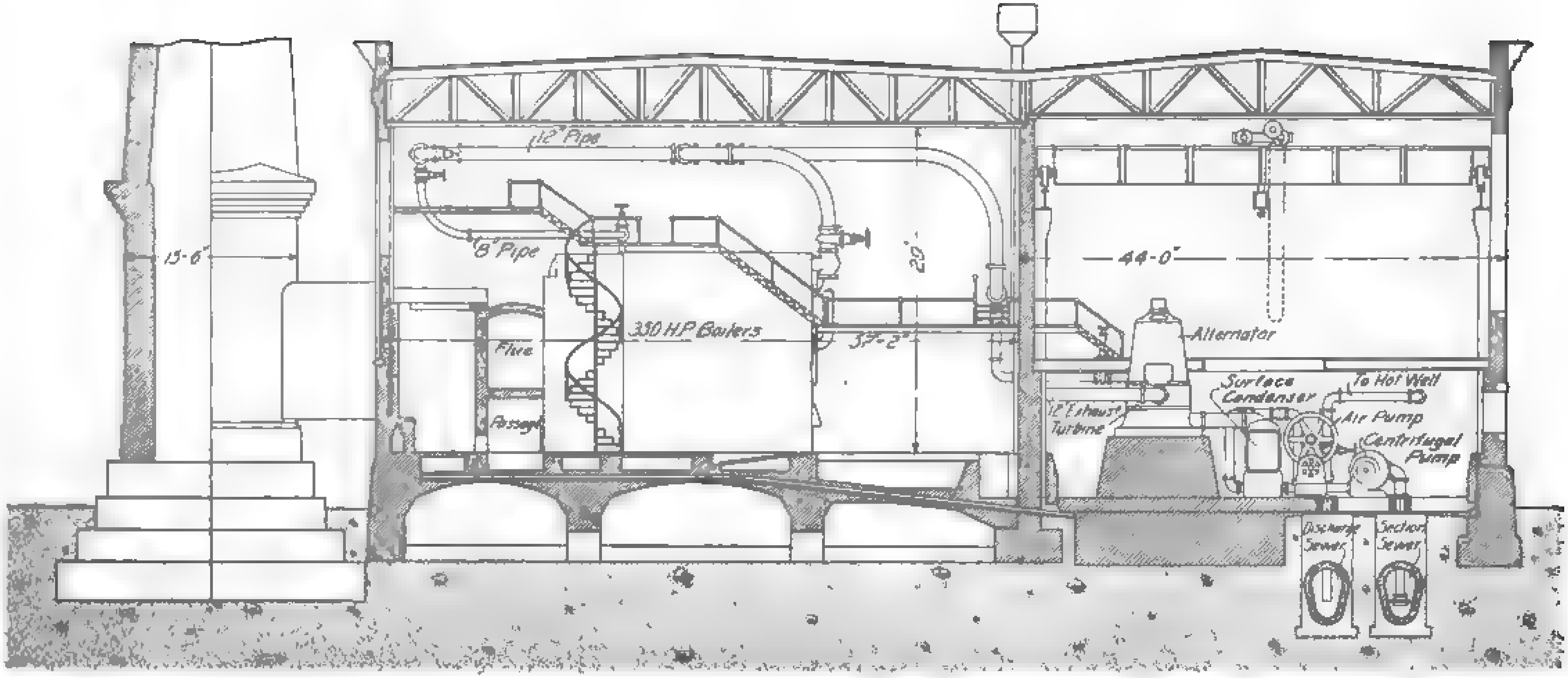

12" Pipe
8" Pipe
15'-6"
Flue
Passage
330 H.P. Boilers
37'-2"
20'
44'-0"
Alternator
Surface Condenser
To Hot Well
Air Pump
Centrifugal Pump
12" Exhaust Turbine
Discharge Sewer
Section Sewer

Fig. 28

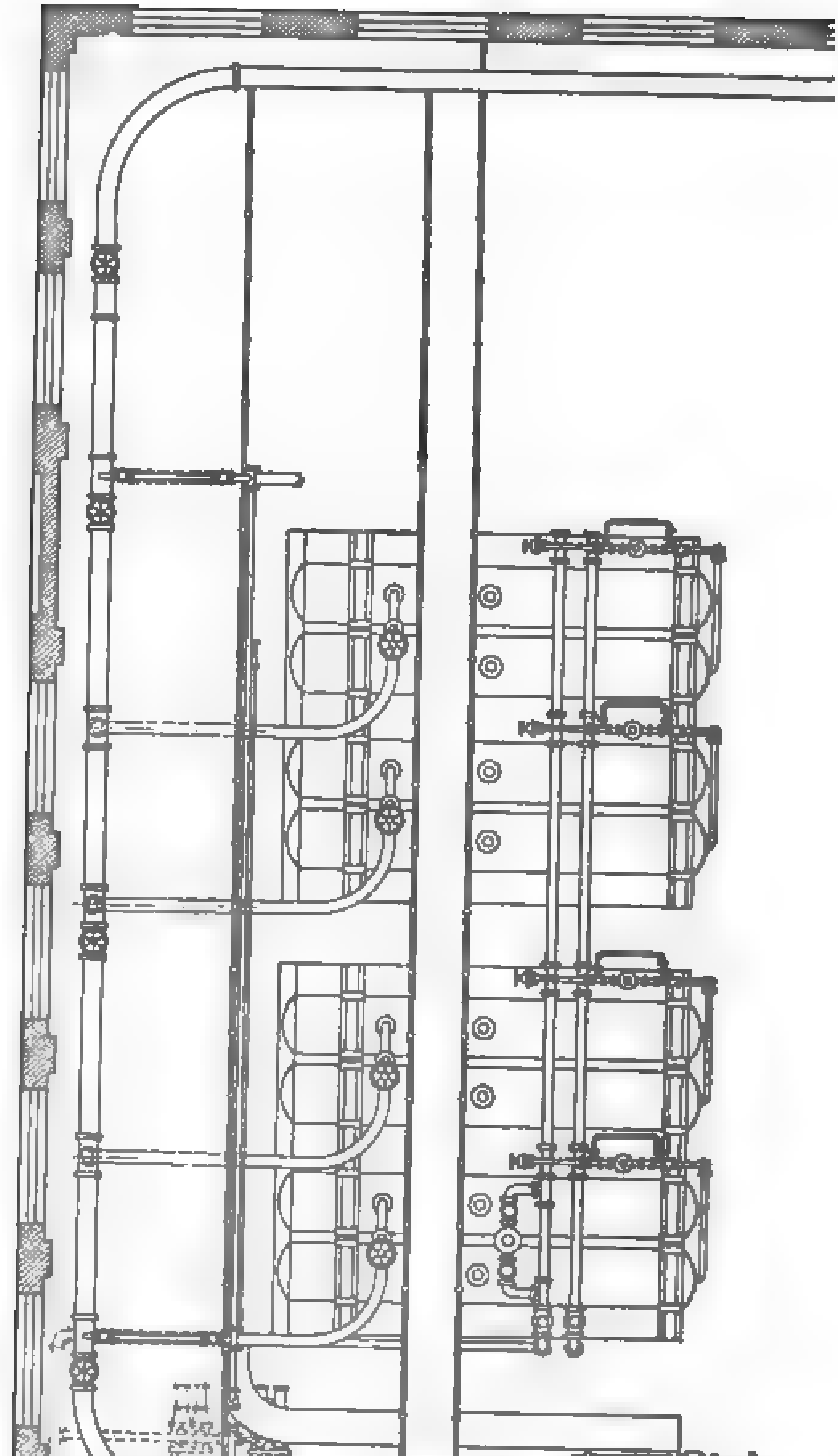
from which it draws its supply of steam, thus allowing the use of smaller steam piping than would otherwise be needed. Jet condensers are used, as shown in Fig. 20, and all auxiliary pumps are driven by electric motors instead of steam engines. The exciters for supplying current to the fields of the alternators are located as shown in Fig. 20, and are driven by direct-connected high-speed engines. The arrangement of the coal-storage plant, boilers, etc. will be apparent from Fig. 20, so that a detailed description is not necessary.

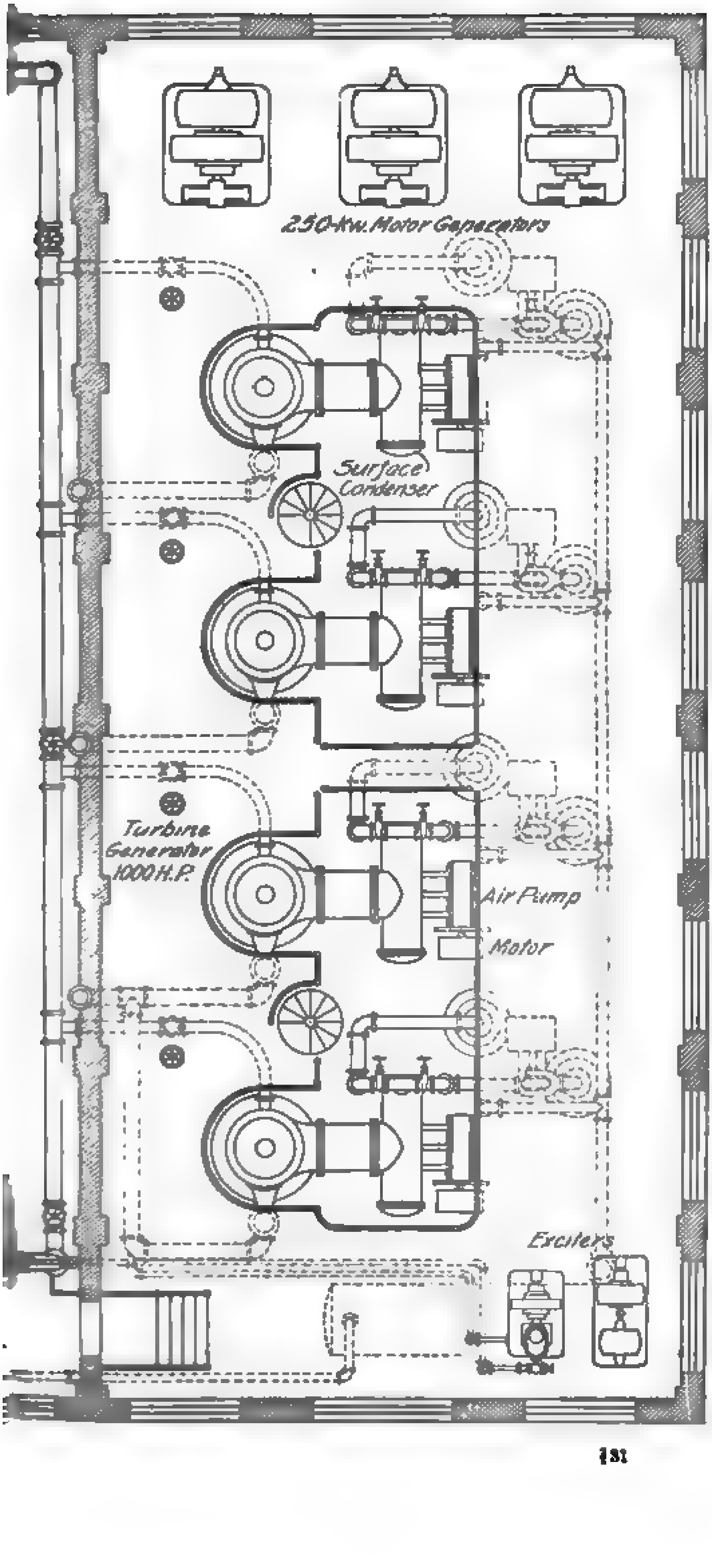
37. **Steam-Turbine Plant.**—The plant shown, Figs. 23 and 24, is of interest, as it represents a steam-turbine installation. The turbines are of the Curtis vertical type, 1,000 horsepower each. On account of the comparatively high speed and vertical arrangement of the turbines, the dimensions of the engine room of the plant are much smaller than would be required for reciprocating engines. The generators are mounted on top of the turbines, the latter being under the engine-room floor. The generators are the only part of the equipment above the floor. In this respect the steam plant bears considerable resemblance to a water-power plant using vertical turbines. Each turbine is about 12 feet in diameter at the base and is operated at 175 pounds steam pressure.

## ELECTRIC GENERATORS AND SPECIAL APPARATUS

38. In connection with electric power stations, it will be necessary to say very little about the **generators**, as these are treated more in detail elsewhere. The only points, therefore, that will be considered are a few relating to the selection of machines and the general requirements to which they should conform.

In all remarks about electric generators it is well to emphasize the point that the design of the generator should be left entirely with the manufacturer thereof; there should be no divided responsibility. The conditions demanded by the service and the contract requirements should be clearly specified and incorporated in the contract, and rigidly


Superheater


250-Kw. Motor Generators
Surface Condenser
Turbine Generator 1000 H.P.
Air Pump
Motor
Exciters

adhered to. Any local engineer who undertakes to specify the design and proportions and windings of an electric generator, and insists on contracting for such, must thereby assume the responsibility for its success or failure, and the manufacturer cannot legally be held liable for satisfactory performance under a divided responsibility. The manufacturing companies, with their broad experience, combination of engineering talent, and splendid facilities are far better equipped to design and furnish a generator that will successfully fill all reasonable conditions of service than any individual engineer can possibly be.

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## REQUISITE CHARACTERISTICS OF GENERATORS

**39.** In selecting a dynamo, it must be remembered that although it is a simple form of machine, it is subject to more sudden strains and overloads than ordinary machines, and is expected to run for long periods with very little attention of any kind. While repairs should very seldom be needed in any generator, necessity is extreme when it does come, and the parts subject to wear and renewal must be so arranged that the work may be done by any good mechanic or armature winder, to the end that the delay, trouble, and expense of sending large parts of the machine to the manufacturer may be avoided.

Certain salient features of construction that apply to any type of generator, motor, or rotary converter should be fulfilled by the manufacturer. All machines must be so designed that an armature coil, a commutator bar, or a field coil may be easily removed and replaced, and, for large machines, without having to lift massive parts or excessive weights. The bearings on all modern generators should be of the continuous, self-oiling type, and must be of the best design. The best practice is in the direction of shafts of large diameters. The shaft should be of the best hammered steel and the journals polished. The length of the journal should be ample to carry the total weight and strain without undue pressure per square inch on the bearing, and the shells of

the bearing should be lined with the best Babbitt metal. The most satisfactory bearings will be so proportioned that the length is about four times the diameter of bore.

**40.** The armature and spider should be stiff and strong, and as light as consistent with the work required, with ample bearing on the shaft and rigidly keyed to it. Modern armatures are of the iron-clad type; the windings are protected from mechanical injury, and the insulating material is placed on the coil in a superior manner.

**41. Insulation of Windings.**—The insulation should withstand an alternating E. M. F. of two to five times the rated E. M. F., tested when heated after 2 hours' constant operation under full load. For example, machines generating up to 400 volts should stand a high-potential test of 1,500 volts; those generating from 400 to 800 volts, a test of 2,000 volts; from 800 to 1,200 volts, a test of 3,500 volts; from 1,200 to 2,500 volts, 5,000 volts; and above 2,500 volts, a test of twice the rated voltage. It must be remembered that high initial insulation, as measured by a galvanometer, does not necessarily imply durability. Such insulating material as carbonizes or cracks under high temperature long continued, and such paints or varnishes as injure the fabric on which they are put, may show very high initial insulation, but a breakdown always comes soon in actual service.

Field coils should be arranged to slip over the magnet cores, or, in large machines, the poles should be so designed that any one can be removed, field coil and all, without disturbing other parts of the machine. The field winding should be so proportioned that the rise of resistance occasioned by rise of temperature will be so slight as to necessitate very little attention to the regulation.

**42.** Commutators should be of sufficient length to afford ample brush surface and of sufficient depth to insure long life without renewal. Half the trouble experienced with carbon brushes is due to insufficient contact surface at the commutator. Only the very best clear mica should be accepted for commutator insulation. Poor mica will gradually

chip away between the bars, no matter how much care and attention is given to the commutator. Very hard mica sometimes wears slower than the bars, causing ridges, which give rise to sparking at the brushes. Commutators must be designed so that oil cannot possibly give trouble.

**43. Brush Holders and Connections.**—The connections to brush studs and cables should be such that none of the current need pass through the spring, otherwise this will soon be annealed by heat and rendered useless. All brush holders, carrying bars, cables, etc. conducting current should be as massive as is consistent with their due proportion of current conducted, and should not show any perceptible rise of temperature under 25 per cent. overload.

**44.** The **field terminals** should be arranged so as to be readily accessible, when the machine is assembled complete, so that they can be easily tightened or disconnected if desired. The frame of the whole machine should be well braced by ribs, and sufficiently strong and rigid to withstand any strain without the slightest spring or vibration.

**45. Capacity and Temperature Rise.**—In specifying the capacity of a generator, or other type of machine, the rise of temperature permitted above the surrounding atmosphere must be clearly stated. Each machine should in every respect be constructed for and guaranteed to carry its full-rated load for a continuous run of 24 hours. The rise in temperature on armature or field windings should not exceed 40° C., above the surrounding atmosphere after a continuous run of 12 hours at full-rated current, voltage, and speed. Immediately succeeding the 12-hour test the machine should be capable of carrying 25 per cent. overload for 2 hours, and during this period should not show a rise in temperature in armature of field windings exceeding 45° C., above the surrounding atmosphere. An allowance of 10° extra should be made for commutator temperature. Each machine should be capable of carrying an overload of 50 per cent. for 30 minutes, and a momentary overload of 75 per cent. at any time during its 24 hours' use under conditions of regular service.

**46. Efficiency.**—The efficiency of a well-designed generator will depend to some extent on the size of the generator, but for a machine of fairly good size will run close to 95 per cent. The total loss of 5 per cent. will be made up about as follows: core and eddy-current loss about 2.27 per cent., $I^2R$ losses about 2.57 per cent., and frictional loss about .16 per cent. The efficiency of generators will vary according to type, capacity, and load and should be clearly set forth in the manufacturer's contract, showing what will be the efficiency at one-fourth load, one-half load, three-fourths load, full load, and 25 per cent. overload.

**47.** When machines are tested to prove the fulfilment of guarantees, such test should be made in the presence of the engineers, the purchaser, and the manufacturer, and should be made in the works of the manufacturer as far as practicable. All instruments required for testing should be furnished by the manufacturer, and correctly calibrated to agree with accepted standards. When machines are tested on the premises of the purchaser, he should provide the load and motive power free of expense to the manufacturer.

## WATER-POWER ELECTRIC STATIONS

**48.** The steam-power station has a decided advantage over the water-power station in the fact that it may be located at any point where fuel is available for raising steam, while water-powers have a restricted value because they are a natural power confined to locations fixed by nature, and capable of development only in the immediate or near vicinity of a fall of water. The energy of water-powers rightly developed and electrically transmitted to centers of population may largely reduce the consumption of coal for electric-supply systems, or under favorable conditions render the use of steam unnecessary.

When contemplating a water-power development for electric transmission certain salient features that are clearly defined, must be fully investigated if one would avoid mistakes. They are as follows:

(*a*) The quantity of water flowing, in cubic feet per second, both in the dryest season and at the maximum flow.

(*b*) The most advantageous location for a dam, assuming that one must be constructed.

(*c*) The most advantageous location for the power station.

(*d*) The total height of the fall of water from the normal level in the forebay at the dam, to the normal level in the tailrace at the discharge.

(*e*) What effects (if any) floods or extra high water will have on the water level, either at the dam or at the tailrace.

(*f*) The market for power if electrically transmitted.

(*g*) The estimated cost of the power development and the cost of transmission.

Too much stress cannot be laid on all these points at the beginning of the enterprise, as the data necessary to insure the capacity and reliability of a water-power requires that measurements should have been made, and that statistics should have been compiled for a period of many years prior to the time when the enterprise is first initiated. The financial success of harnessing a water-power, to the average business man, seems to be a self-evident proposition. He sees millions of foot-pounds of energy which, when transformed by electric generators, is to him the same as is developed by coal when burned to generate steam for driving engines. Suitable mechanism must be interposed to deliver the force of the falling water to a revolving shaft, and apparently there is a perpetual supply of power, but between this proposition and the actual attainment of the results there are many details that the business man does not readily grasp, and for the success of the enterprise he must rely on the experienced engineer. The price paid for electric power depends on the demand, the same as for any other commodity, and there are many locations of excellent water-powers where there is not a market for power even within the commercial limits of successful electric transmission.

The margin of profits in water-powers within the territory where coal can be distributed economically is often doubtful and must be investigated with great care. It is of course

recognized that in exceptional instances, such as the flow of water through Niagara Falls, there can be no doubt regarding reliability. Almost all rivers and streams have variations in flow during certain seasons of the year, that are occasioned by local rains, melting of snows, or other meteorological conditions, which must be thoroughly and exhaustively investigated in every individual instance.

**49.** The area and characteristics of the watershed supplying a river or other stream should be a subject of most careful investigation and study. For instance, a watershed of 5,000 square miles area, having gentle slopes well covered with forest growths and subject to copious rainfall throughout almost every month of the year, will be more certain to give a fairly constant flow of water than would an equal area of steep and rocky mountain slopes with little verdure, where the rainfall would quickly run off in sudden floods and periods of low water would be experienced between times. Again, where high mountain ranges perpetually covered with snow exist, the melting snows afford quite a reliable flow of water, except during the winter months if the locality be in the northern latitudes.

It is quite customary to assume that the ordinary water-power has the possibility of a much larger power development than that for which it is really reliable, whereas its absolute reliability and capacity must be based on the minimum flow of water during the dryest season of the year, and such minimum flow should be verified by the most exhaustive investigation, which must be entirely devoid of all personal views and based solely on practical and unprejudiced statistics.

**50. Storage of Water.** It is frequently possible in favorable localities to build a system of storage reservoirs that may hold sufficient water to carry over a short period of dry weather or that will afford the extra water supply requisite to carry the station over the peak loads of daily service. If the water is held for 12 hours and the whole quantity used the next 12 hours, the power of the stream will be doubled for that time.

**51. Definitions.**—Following are definitions of some terms used in connection with certain features of water-power development between dam and power station.

*Forebay*, that part of a mill race where the water starts to flow in the direction of the wheel.

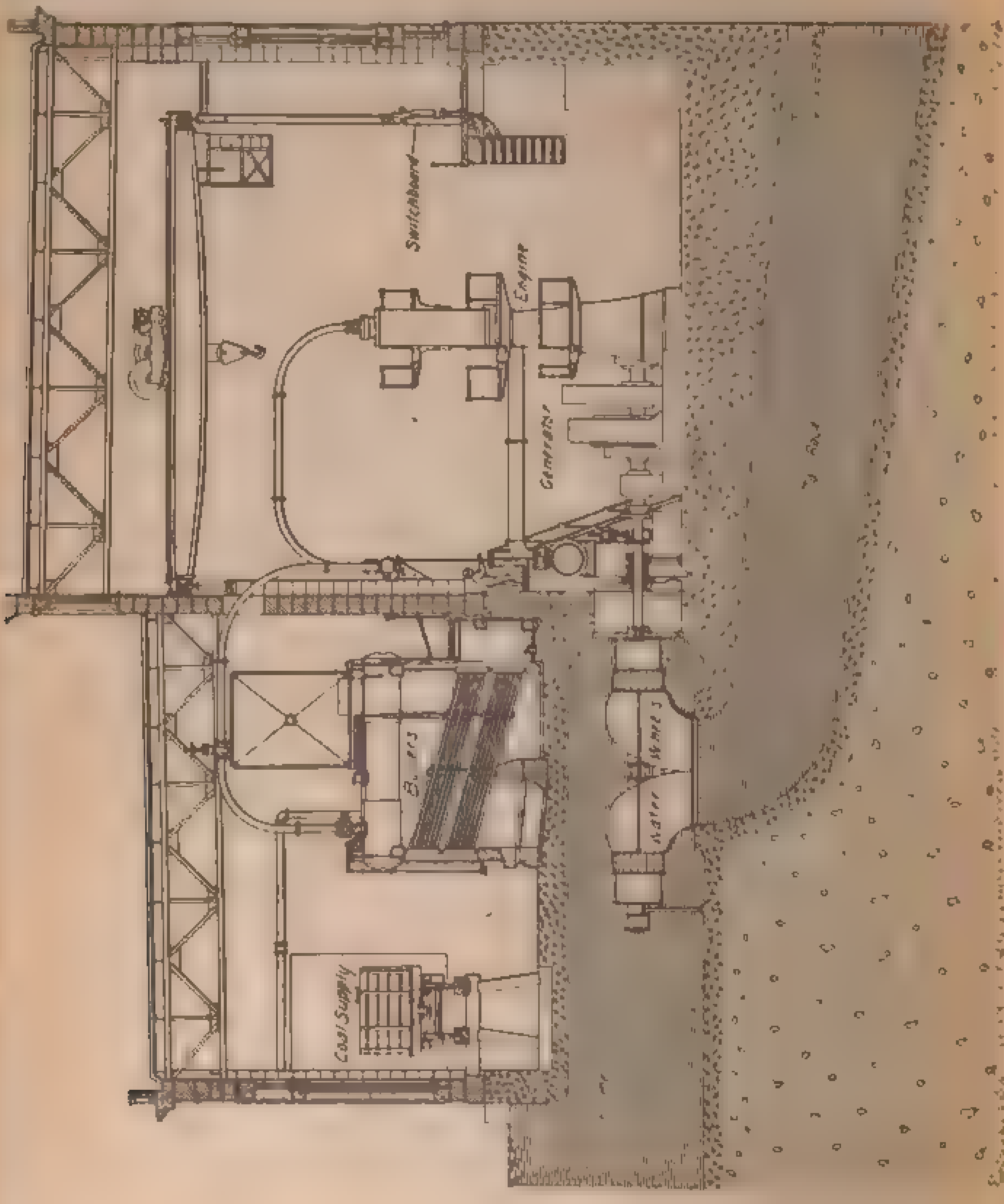
*Flume*, an open or covered artificial channel or conduit for conducting the water from the forebay to the wheel.

*Penstock*, that part of the channel, conduit, or trough supplying water to the wheel that extends between the raceway and the gate through which the water flows to the wheel.

**52. Combined Water- and Steam-Power Plants.** Where it is undertaken to develop a greater power than can be reliably attained during the period of minimum flow it will be found necessary in many instances to reenforce the water-power station by steam power. Fig. 25 illustrates a station of this type, the generator being so arranged that it can be driven either by the engine or waterwheels. The main object to be attained in the development of a water-power is greater economy in the production of power than can be secured by steam.

This object is frequently attained with satisfactory results, and where water-power and steam power are combined the use will be varied according to the seasons, as shown in the following schedule for 1 year's service in a station in Massachusetts:

| 1899 | Per Cent. Energy From Water | Per Cent. Energy From Steam |
|---|---|---|
| July | 92.5 | 7.5 |
| August | 92.0 | 8.0 |
| September | 90.5 | 9.5 |
| October | 54.0 | 46.0 |
| November | 94.0 | 6.0 |
| December | 75.0 | 25.0 |
| 1900 | | |
| January | 76.0 | 24.0 |
| February | 94.0 | 6.0 |
| March | 100.0 | 0.0 |
| April | 100.0 | 0.0 |
| May | 100.0 | 0.0 |
| June | 100.0 | 0.0 |


Switchboard
Engine
Generator
Coal Supply

**53.** As a general rule, those who attempt water-power development should expect to make a larger initial investment to place the enterprise on a working basis than will be necessary with steam power of equal capacity. A good steam plant, according to its type, degree of economy, and market prices, can be installed at a cost of from \$30 to \$75 per horsepower, whereas the expenditures involved to develop a water-power based on utilizing 70 per cent. of the power of the water, including the wheels and necessary appurtenances, will cost from \$75 to \$150 per horsepower, and if the water-power is deficient in capacity the cost of steam power to reenforce and insure its reliability should be added thereto. The total investment in each case should be carefully compared, and the interest on extra cost added where properly chargeable. After the initial cost of a water-power plant has been met, even though it be larger than for a steam plant, the recompense comes in reduced annual operating expenses. Where a steam plant must be used as an auxiliary, the operating expenses are increased by the additional cost of fuel, and for labor of firemen and engineers.

**54.** Between the water flowing in the stream and the point where the power may be utilized, the following elements must be considered:

(*a*) The best method of developing the power in the building of a dam and canal sluiceway or pipe, the placing of the power station, and the type of wheels to be employed.

(*b*) The type of generator and dynamo to be used and the method of imparting the power of the wheel to the shaft of the dynamo, whether by direct connection or by belting or gearing.

(*c*) The potential at which the current shall be generated; the distance over which the power must be transmitted will determine whether the original potential from the generator can be delivered at the point where the power is used, or whether step-up transformers are necessary to raise the potential of the current at the power station and step-down transformers to reduce it at the point where it is utilized.

(*d*) The electrical conductors necessary for conducting the energy developed at the station to the point where it is used.

(*e*) The step-down transformers that for long-distance transmission receive the current from the transmission lines and reduce the high potential to that available for commercial distribution.

(*f*) The method of reconverting the energy transmitted into power that may be applied to the driving of machinery or other appliances for industrial purposes.

Each one of these successive stages of conversion and transformation of energy involves a certain percentage of loss.

**55.** The most economical point for the development of a water-power may be so distant from any point of possible utilization or so undesirable for the location of any industry of considerable size that it cannot be made remunerative; therefore, the distance, which involves an expense in electrical conductors and pole-line construction, and the cost thereof require to be very accurately estimated, to the end that the true comparison of cost between a water-power station at its distant location and the cost of a steam-power station at the point where the power is desired may be arrived at. These points are not mentioned to discourage the development of water-powers, but to put the engineer on his guard that he may analyze with care the possible objections, and if all features are favorable he is then warranted in approving the proposed development.

## MEASUREMENT OF WATER-POWER

**56. Measuring the Volume of Water.**—In the improvement or development of a water-power it is necessary to know the amount of power that can be depended on as reliable; it is not advisable to rely on any superficial examination, and it is very necessary that accurate measurements of capacity and fall should be made. The quantity of water flowing in a small stream can be estimated by the use

of the **weir**, which is a partially submerged orifice through which the stream is forced to overflow. Use a board long enough to reach across the stream, with each end set in the bank, as shown in Fig. 26. Cut a notch in the board deep enough to pass all the water, and long enough to reach about two thirds across the stream. This is called *weir dam*. The bottom and ends of the notch *a* in the board should be beveled on the down-stream side, leaving the upper edge almost sharp. The stake *b* should be driven in the bottom


FIG. 26

of the stream, several feet from the board, on a level with the sharp edge of notch *a*, this level being easily found when the water is beginning to spill over the notch.

When the water has reached its greatest depth, a careful measurement can be made of the depth over the stake. The dotted lines represent the level *d* of the running water, and the level *e* of the top of the stake. The distance between these lines gives the true depth, or spill over the weir board; if measured directly on the notch, the currents of water

would reduce the depth. The surface water after passing from the board should not be nearer the notch *a* than 10 inches.

The nature of the channel above the board should not be such as to force or hurry the water; but must be amply wide and deep to allow the water to approach the notch quietly. For convenience of calculation Table VII is given.

## TABLE VII

### WEIR TABLE—FLOW FOR EACH INCH IN WIDTH

| Inches | | 1/8 | 1/4 | 3/8 | 1/2 | 5/8 | 3/4 | 7/8 | Inches |
|---|---|---|---|---|---|---|---|---|---|
| 1 | .40 | .47 | .55 | .65 | .74 | .83 | .93 | 1.03 | 1 |
| 2 | 1.14 | 1.24 | 1.36 | 1.47 | 1.59 | 1.71 | 1.83 | 1.96 | 2 |
| 3 | 2.09 | 2.23 | 2.36 | 2.50 | 2.63 | 2.78 | 2.92 | 3.07 | 3 |
| 4 | 3.22 | 3.37 | 3.52 | 3.68 | 3.83 | 3.99 | 4.16 | 4.32 | 4 |
| 5 | 4.50 | 4.67 | 4.84 | 5.01 | 5.18 | 5.36 | 5.54 | 5.72 | 5 |
| 6 | 5.90 | 6.09 | 6.28 | 6.47 | 6.65 | 6.85 | 7.05 | 7.25 | 6 |
| 7 | 7.44 | 7.64 | 7.84 | 8.05 | 8.25 | 8.45 | 8.66 | 8.86 | 7 |
| 8 | 9.10 | 9.31 | 9.52 | 9.74 | 9.96 | 10.18 | 10.40 | 10.62 | 8 |
| 9 | 10.86 | 11.08 | 11.31 | 11.54 | 11.77 | 12.00 | 12.23 | 12.47 | 9 |
| 10 | 12.71 | 13.95 | 13.19 | 13.43 | 13.67 | 13.93 | 14.16 | 14.42 | 10 |
| 11 | 14.67 | 14.92 | 15.18 | 15.43 | 15.67 | 15.96 | 16.20 | 16.46 | 11 |
| 12 | 16.73 | 16.99 | 17.26 | 17.52 | 17.78 | 18.05 | 18.32 | 18.58 | 12 |
| 13 | 18.87 | 19.14 | 19.42 | 19.69 | 19.97 | 20.24 | 20.52 | 20.80 | 13 |
| 14 | 21.09 | 21.37 | 21.65 | 21.94 | 22.22 | 22.51 | 22.79 | 23.08 | 14 |
| 15 | 23.38 | 23.67 | 23.97 | 24.26 | 24.56 | 24.86 | 25.16 | 25.46 | 15 |
| 16 | 25.76 | 26.06 | 26.36 | 26.66 | 26.97 | 27.27 | 27.58 | 27.89 | 16 |
| 17 | 28.20 | 28.51 | 28.82 | 29.14 | 29.45 | 29.76 | 30.08 | 30.39 | 17 |
| 18 | 30.70 | 31.02 | 31.34 | 31.66 | 31.98 | 32.31 | 32.63 | 32.96 | 18 |
| 19 | 33.29 | 33.61 | 33.94 | 34.27 | 34.60 | 34.94 | 35.27 | 35.60 | 19 |
| 20 | 35.94 | 36.27 | 36.60 | 36.94 | 37.28 | 37.62 | 37.96 | 38.31 | 20 |
| 21 | 38.65 | 39.00 | 39.34 | 39.69 | 40.04 | 40.39 | 40.73 | 41.09 | 21 |
| 22 | 41.43 | 41.78 | 42.13 | 42.49 | 42.84 | 43.20 | 43.56 | 43.92 | 22 |
| 23 | 44.28 | 44.64 | 45.00 | 45.38 | 45.71 | 46.08 | 46.43 | 46.81 | 23 |
| 24 | 47.18 | 47.55 | 47.91 | 48.28 | 48.65 | 49.02 | 49.39 | 49.76 | 24 |

The figures 1, 2, 3, etc. in the first vertical column of the table are the inches depth of water running over the notch of the weir; the top horizontal row of figures shows fractional parts of an inch, and the body of the table shows the cubic feet and the fractional parts of a cubic foot that will pass each minute, for each inch and fractional inch depth of water in notch, from 1 to 25 inches. For example, if the depth of water were $6\frac{5}{8}$ inches there would be 6.85 cubic feet per minute flowing over the weir, the number 6.85 being found in the $\frac{5}{8}$ column opposite 6 in the left-hand column. Each of these results is for 1 inch only in width of weir; for any particular number of inches width of weir notch, the result obtained in the table must be multiplied by the number of inches of breadth or length the weir notch may be.

EXAMPLE.—The notch in the board is 20 inches wide, and the water at the stake $5\frac{1}{4}$ inches deep. How many cubic feet of water will flow over the weir per minute?

SOLUTION.—Take the figure 5 in the first vertical column, Table VII, and follow the horizontal line of figures until a vertical column is reached, containing $\frac{1}{4}$ at the top. At the intersection is found 5.18 cu. ft. This is the quantity of water passing for each inch in width; but the supposed weir is 20 in. in width; therefore, this result must be multiplied by 20, which gives 103.6 cu. ft. per min. Ans. The same method may be applied to any depth from 1 to 25 inches.

**57. Measurement of Flow in Large Streams.** Where it is impossible to construct a weir, the simplest method is to ascertain the mean velocity of the stream, in feet per minute, and its cross-section in square feet, then multiply these amounts together and thus obtain the required flow in cubic feet per minute. The velocity can be estimated by throwing floating bodies into the stream and noting the time required for them to pass over a measured distance between two lines $a'$, $b'$, Fig. 27. But it must be remembered that the velocity is greatest in the center of the stream, and near the surface, and that it is least near the bottom and sides. However, the velocity at the center can be measured and from this the mean velocity can be estimated, as it is known from reliable experiments that the mean velocity will be 83 per cent. or approximately four-fifths of the velocity of the surface.

The cross-section may be estimated by measuring the depth of the stream, at a number of points an equal distance apart, as illustrated in Fig. 27, at *a*, *b*, *c*, *d*, etc. The sum of these depths multiplied by the distance, in feet, between any two points gives the cross-sectional area of the stream. The product of the cross-section of the stream, in square feet, and the average or mean velocity of the water, in feet per minute, gives the quantity of water that the stream affords, in cubic feet per minute. The measurements at *a*, *b*, *c* must be in feet or fractions of a foot.

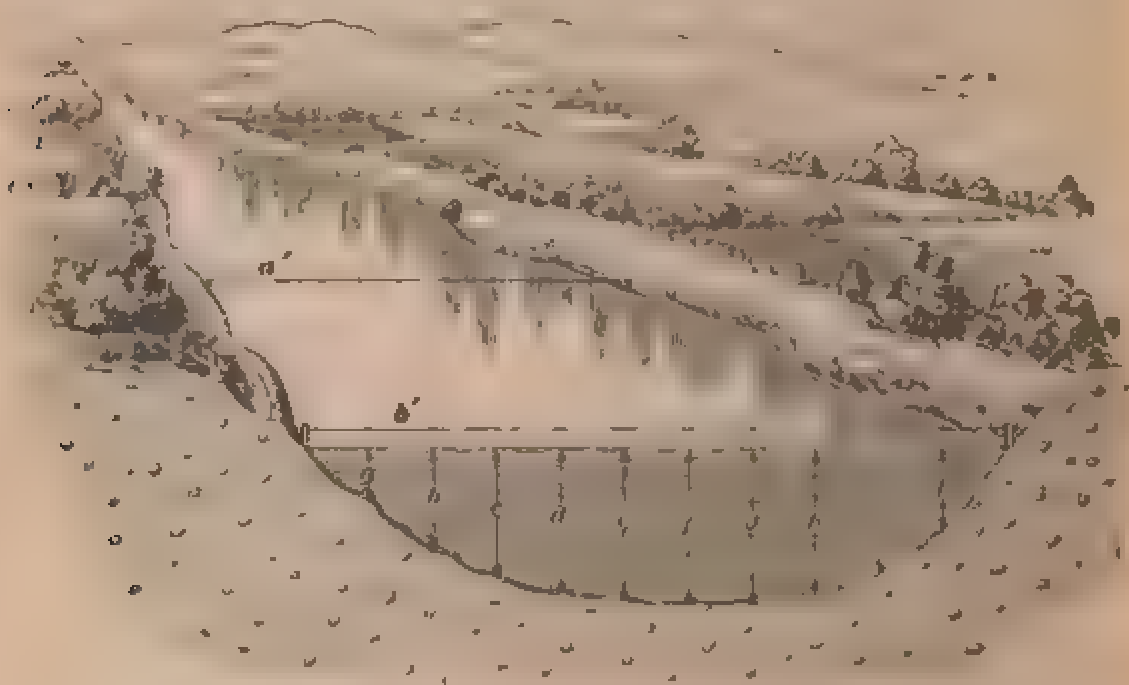


FIG. 27

**58. Measurement of Head or Fall.** The next point necessary in the improvement of a water-power is to ascertain the amount of *head* or *fall*. The head of water is the difference between the level of the water in the forebay, or headrace, and the level of the water in the tailrace, or aqueduct, that carries the water from the wheel. The head is usually determined with an engineer's level, by running a level from a point at the upper level of water to a point at the lower level of water. The vertical distance between the two points is the standing head or fall. If the stream is liable to floods backing up the water in the tailrace, the difference between the normal level and flood level in the tailrace must be

allowed for, since under such abnormal conditions the net value of the power will be reduced in proportion.

A head of water can be utilized in any of the following ways: by its weight, as in the overshot wheel; by its pressure, as in the turbine wheel; by its impulse, as in the undershot, Pelton, or other type of impulse wheel. The *gross power* of a fall of water is the product of the weight of water discharged in a unit of time, and the total head.

**59. Estimation of Horsepower.**—The horsepower of a stream may be found by multiplying the volume of flow per minute of the stream by 62.5 pounds, which is the approximate weight of water per cubic foot, and this product again by the head or fall, in feet, which will give the foot-pounds for the stream in question. This product divided by 33,000 will give the theoretical horsepower of the stream. This may be expressed as follows:

$$\text{Theoretical horsepower} = \frac{62.5\,VH}{33{,}000} \qquad (3)$$

where $V$ = volume of flow, in cubic feet per minute;
$H$ = effective head, in feet.

To determine the net mechanical horsepower that may be obtained at the shaft of the wheel, there must be deducted from the theoretical horsepower the loss in head by the friction of the water in flowing through the channels between the forebay and the wheels and the loss in the wheel itself, which will vary according to the efficiency of the wheel.

EXAMPLE.— 10,500 cubic feet of water are delivered each minute by a stream under a head of 50 feet. How many horsepower will be available at the shaft of the wheel if 5 per cent. is lost through friction before the water reaches the wheel and if the wheel has an efficiency of 75 per cent.?

SOLUTION.—From formula **3**, the theoretical horsepower will be equal to $\frac{62.5 \times 10{,}500 \times 50}{33{,}000} = 994$ H. P., approximately. Of this, 5 per cent. is lost in friction so that the horsepower delivered to the wheel will be $994 \times .95$. The wheel has an efficiency of 75 per cent.; hence, the power delivered at the shaft of the wheel will be $994 \times .95 \times .75 = 708$ H. P. Ans.

TABLE VIII

HORSEPOWER PER CUBIC FOOT OF WATER PER MINUTE FOR VARIOUS HEADS

| Heads Feet | Horsepower | Heads Feet | Horsepower |
|---|---|---|---|
| 1 | .0016098 | 320 | .515136 |
| 20 | .032196 | 330 | .531234 |
| 30 | .048294 | 340 | .547332 |
| 40 | .064392 | 350 | .563430 |
| 50 | .080490 | 360 | .579528 |
| 60 | .096588 | 370 | .595626 |
| 70 | .112686 | 380 | .611724 |
| 80 | .128784 | 390 | .627822 |
| 90 | .144892 | 400 | .643920 |
| 100 | .160980 | 410 | .660018 |
| 110 | .177078 | 420 | .676116 |
| 120 | .193176 | 430 | .692214 |
| 130 | .209274 | 440 | .708312 |
| 140 | .225372 | 450 | .724410 |
| 150 | .241470 | 460 | .740508 |
| 160 | .257568 | 470 | .756606 |
| 170 | .273666 | 480 | .772704 |
| 180 | .289764 | 490 | .788802 |
| 190 | .305862 | 500 | .804900 |
| 200 | .321960 | 520 | .837096 |
| 210 | .338058 | 540 | .869292 |
| 220 | .354156 | 560 | .901488 |
| 230 | .370254 | 580 | .933684 |
| 240 | .386352 | 600 | .965880 |
| 250 | .402450 | 650 | 1.046370 |
| 260 | .418548 | 700 | 1.126860 |
| 270 | .434646 | 750 | 1.207350 |
| 280 | .450744 | 800 | 1.287840 |
| 290 | .466842 | 900 | 1.448820 |
| 300 | .482940 | 1,000 | 1.609800 |
| 310 | .499038 | 1,100 | 1.770780 |

Table VIII gives the horsepower of 1 cubic foot of water per minute under heads of from 1 foot up to 1,100 feet, based on a wheel efficiency of 85 per cent. and exclusive of any loss due to friction after leaving the forebay.

## DAMS

**60.** The construction of dams may be considered under four classes of work: (*a*) The *log*, or *brush*, *dam*, (*b*) the *frame dam*, (*c*) the *crib dam*, (*d*) the *masonry dam*. Under each class of construction there are many variations in detail. The first two classes are not worth considering in connection with the subject in hand.

In the building of dams the following six essential features must be thoroughly provided for:

(*a*) The foundation must be absolutely substantial and secure.

(*b*) The thickness and weight of the structure and its attachment to the foundation must be such as to withstand the pressure or thrust of the water in the reservoir above the dam.

(*c*) The shape of the dam must be such that it will not in any manner be injured by ice expansion when the water is frozen.

(*d*) Discharge from the slope or face of the dam must be such that the sheet of water flowing over will maintain a continuous and unbroken column free from atmospheric interferences; there must not be a broken flow followed by a rebound that causes vibration and tremulous motion in the dam.

(*e*) The shape of the dam must be such that the discharge of the water from the slope will not wear away the bed of the stream, or the footing at the base of the dam.

(*f*) The entire structure must be tight against leakage; capillary attraction must be avoided, or leaking currents of water may in time wear away the banks or undermine the foundations.

Fig. 28 shows a sectional view of a masonry-and-concrete dam. Improper discharge of water over the crest of a dam

may set up swirling, eddy, direct, and reversed currents, which are sure to produce centrifugal and centripetal currents that will scour the banks and abutments and deepen the channel.

Arched dams have, by many, been preferred to straight dams, because of the mistaken notion that they obtain an additional support from their abutments, which is not a fact. In architecture, the weight of the arch and its load is thrown against the abutments, and they to a large extent support the masonry above and extending over the arch. With the arched dam the question is not one of gravity, but of force exerted horizontally. The horizontal pressure of the water

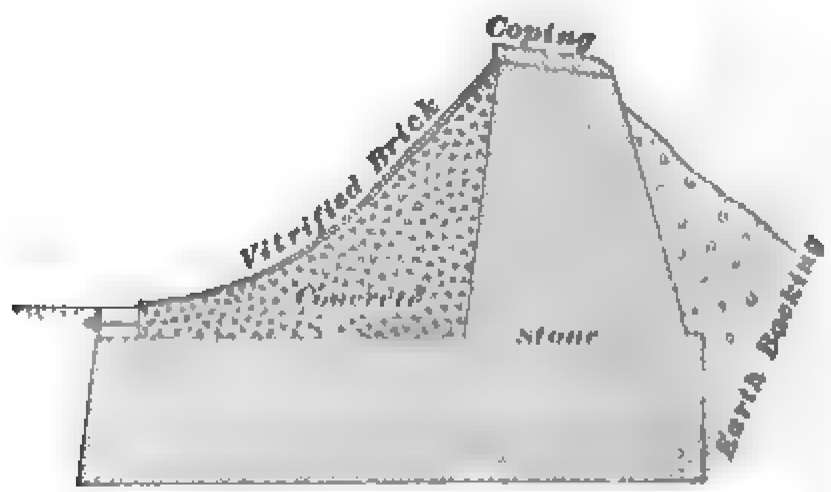



FIG. 28

is about the same at all points throughout the length of the arch and there can be no end thrusts. The water flowing from an arched dam is liable to create more friction than would occur with a longitudinal flow from a straight dam.

**61.** The first cost of a dam whether of stone or timber, its rapid impairment, the important part that it bears in relation to the whole enterprise, the cost of maintenance, and the uncertainty of its stability are matters of such vital importance that the work should be left to an engineer especially skilled in this line. The dam may be regarded largely as the very foundation of a water-power enterprise, and it is poor economy that does not employ the best skill in its design and construction.

### VELOCITY OF FLOWING AND FALLING WATER

**62.** The theoretical velocity of water flowing from an orifice is the same as the velocity of a falling body that has fallen from a height equal to the head of water. The quantity of water discharged through the pipe or open channel depends on the head (that is, the vertical distance between the level surface of the still water at the entrance end of the channel and the level of the center at the discharge end), the length of the channel, the character of its interior surface as to smoothness, and the number and radius of the bends.

The total head operating to cause a flow is divided into three parts: the *velocity head*, which is the height through which a body must fall to acquire velocity; the *entry head*, or that required to overcome the resistance at the entrance to the channel; and the *friction head*, or the head required to overcome the frictional resistance within the channel or pipe. In ordinary cases where the work is properly designed, the sum of the velocity and entrance heads can be disregarded, as they rarely exceed 1 foot.

As already indicated, there are certain losses that must be deducted from the gross theoretical horsepower of a falling stream to determine the net mechanical horsepower available for useful work. Much will depend on the local conditions and the nearness of the power station to the forebay. If immediately adjacent, as shown in Fig. 37, the loss by friction through connecting flumes or penstocks will be almost negligible. If the water is conducted from the forebay to the wheels through a closed pipe or flume, the loss of head in a pipe increases directly with the length, with the square of the velocity, and with the roughness of the pipe; it decreases as the diameter of the pipe increases, and is independent of the pressure or head of water.

### LOSS OF HEAD DUE TO VELOCITY IN OPEN CHANNELS

**63.** When a stream leaves the still water of a lake or reservoir at a given velocity, there will be a certain loss of head to generate that velocity; that is to say, the stream in

the conduit must be lower than the still water in the reservoir in order to create the velocity required. The velocity will vary at the entrance according to the shape of the entrance and the position of the gate, and there is a loss at the entrance due to contraction at the sides of the aperture. When the channel is long, there is not only a loss of head due to the velocity, but also a loss by friction against the sides and the bottom. If the channel is maintained of equal cross-sectional area from end to end the loss of head increases uniformly throughout the length, but if the cross-sectional area of the channel is increased from the entrance to the discharge end, the friction will be decreased.

The discharge of open water courses may be determined experimentally by observing the velocity of the current, and measuring the cross-sectional area of the stream. To do this correctly requires the mean velocity throughout the section, which is not obtainable by observation and must be determined as described in Art. 57.

**64. Influence of Inside Surface of Flumes or Pipes.**—The shape and inner surface of the channel, conduit, or pipe through which the water flows, and which, by friction, reduces its velocity, is a highly important factor in the development of a water power. Extreme care should be observed to have these surfaces as smooth as practicable, and with bends the fewest possible and of long radius. Channels having their inner surfaces made of well-planed timber in perfect order and alinement, of glazed or enameled stoneware, iron pipes, cement finish with stone surface in good condition, unplaned timber, well laid brickwork, rough-faced brickwork, well dressed stonework, or rubble masonry in cement, will afford friction increasing in the order in which the surfaces have been given. Furthermore, a channel or sluiceway composed of earth with the banks trimmed uniformly and laid smooth and in good order will offer more friction than any of the surfaces above mentioned, and as these earthen banks are obstructed by stones, rocks, weeds, and other surfaces of a rough character, and as they become

somewhat disintegrated with alternate freezing and thawing in northern latitudes, the friction will be increased and the velocity of the flow of water reduced.

**65. Loss of Head in Smooth Straight Pipes.**—The loss of head, expressed in feet, due to the flow of water through smooth straight pipes may be found approximately by means of the formula

$$h = \frac{k L v^2}{d} \qquad (4)$$

where $h$ = loss of head expressed, in feet;
$L$ = length of pipe, in feet;
$v$ = velocity, in feet per second;
$d$ = diameter of pipe, in inches;
$k$ = .0056 for pipes up to 6 inches diameter; .0047 for pipes between 6 inches and 21 inches; .0037 for pipes between 21 inches and 48 inches; .0028 for pipes between 48 inches and 72 inches; and .0019 for pipes larger than 72 inches.

This formula will give approximate results within at least 10 per cent. of correctness for smooth straight pipes.

EXAMPLE.—What will be the loss of head in 500 feet of 36-inch pipe through which water is flowing at the rate of 10 feet per second?

SOLUTION.—We have $L = 500$, $v = 10$, $d = 36$, and $k = .0037$;

$$h = \frac{.0037 \times 500 \times 10^2}{36} = 5.14 \text{ ft.} \quad \text{Ans.}$$

## WATERWHEELS

**66. Waterwheels** may be divided into the following classes: (*a*) *Overshot wheels*, (*b*) *undershot and breast wheels*, (*c*) *turbines*, (*d*) *impulse wheels*. The first two classes may be passed over without comment, as they are seldom, if ever, used in modern electric water-power plants.

Overshot wheels have been known to give an efficiency of 75 per cent., but the average performance does not exceed 60 per cent. The efficiency of turbines will range, according to their design and the speeds at which they are operated, from 50 to 75 per cent., very rarely reaching as high as 83 per cent. The *draft tube*, or *suction tube*, taking the discharge between the turbine and the tailrace, helps to improve the efficiency, and its effect is included in the above figures. The falling column of water in the draft tube creates a suction on account of the vacuum formed, but perfect vacuum is not obtained. Impulse wheels of the Pelton or similar types are claimed to have an efficiency of 80 to 85 per cent.

### TURBINES

**67.** In the **turbine waterwheel**, the water acts on a series of curved vanes and the rotating part is acted on by a continuous flow of water through the turbine. The passages between the wheel vanes are always completely filled with water and the forces that act on the wheel vanes are: first, a certain amount of static pressure; second, the pressure caused by the change in direction of the moving water; and third, a pressure due to the reaction of the water as it issues from the wheel vanes. In most cases, the greatest of these forces is the pressure caused by the change in the direction of the moving water in its passage through the wheel.

The turbine wheel is a thoroughly reliable hydraulic motor, and under practical use for many years has been improved to such an extent as to incorporate the largest durability with high efficiency and the greatest ease of operation. Turbines are made in many different forms; they may be arranged for vertical or horizontal shafts and connected single or double on the same shaft; they may or may not be enclosed in casings and may be used with or without draft tubes.

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### EXAMPLES OF TURBINES

**68.** Turbines are frequently classed according to the direction of the flow of water through them. For example, the water may enter parallel to the shaft and be discharged parallel to the shaft also; such wheels are known as *parallel-flow*, or *axial-flow, turbines*. Or, the water may flow in at the center and be discharged outwards at the circumference of the wheel, constituting what is known as an *outward-flow turbine*. In others, the flow may be radial but reversed in direction, flowing from the circumference to the center and making an *inward-flow turbine*; in many American turbines, the vanes are so shaped that the water is discharged in an axial direction, thus making a *mixed-flow turbine*.

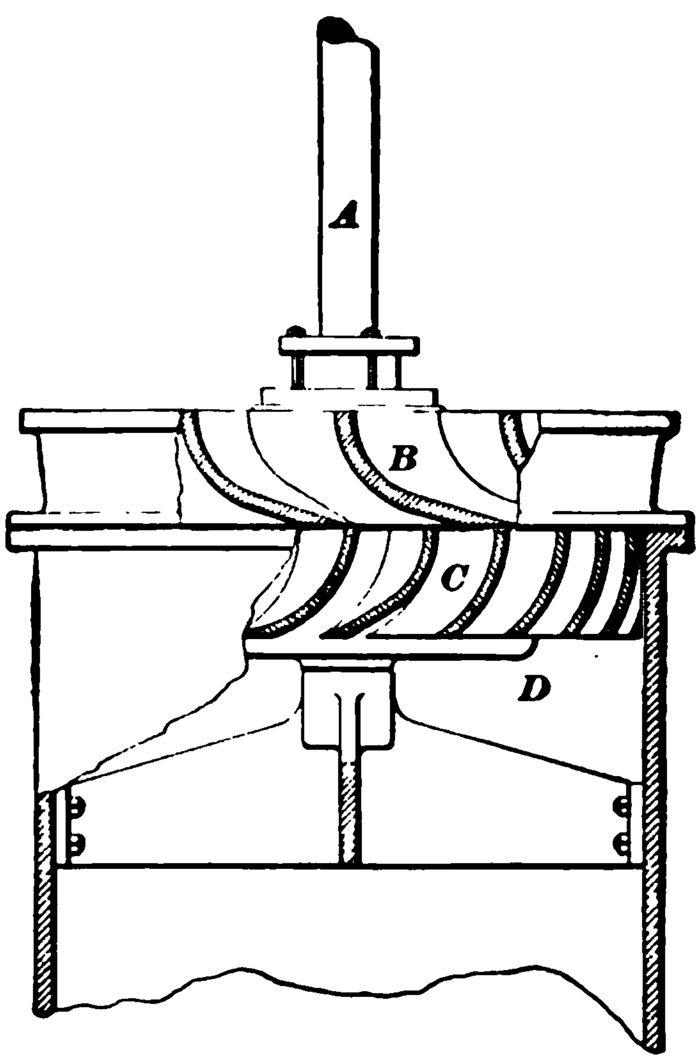


FIG. 29

**69.** No matter what the direction of flow may be, turbines consist of two essential parts: first, a series of curved guide vanes, which are fixed and serve to guide the water to the wheel in the most efficient manner so as to deliver it in a direction where it will act to the best advantage; and second, a wheel, or *runner*, which also carries curved

vanes that change the direction of the water passing through the wheel and take up the pressure, which is effective in driving the wheel around.

Fig. 29 illustrates the essential parts of a vertical-shaft, axial-flow turbine. The water flows in, from above, through the fixed guide vanes *B*, acts on the curved vanes of the runner *C*, and is discharged into the draft tube *D*. The general direction of the water is always parallal to the shaft *A* and the spaces between the vanes is at all times filled with water.

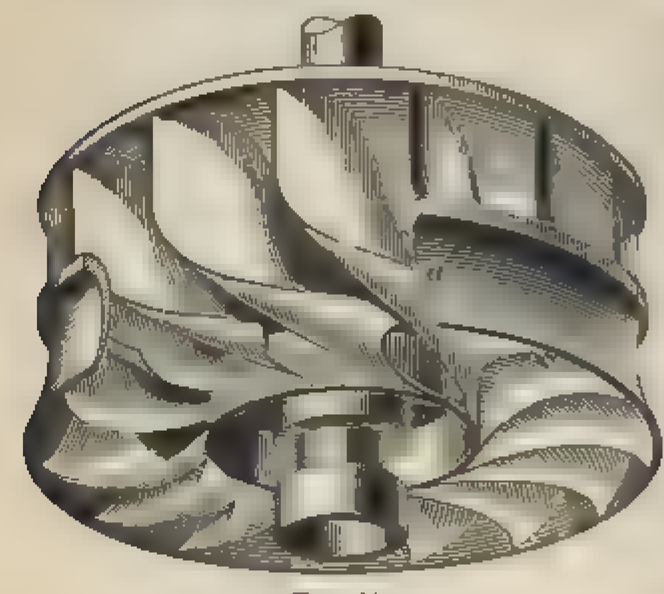



FIG. 30

Fig. 30 shows the runner for a *Risdon turbine*, which is of the mixed-flow type. The vanes have a double curvature, and the water is delivered to the upper part in a radial direction by means of suitable guide vanes, but owing to the curvature of the runner vanes it is discharged in an axial direction. The band *a* serves the double purpose of strengthening the wheel and of making the proper form for the passage of the water through the lower part of the wheel, confining it on all sides.

**70.** Fig. 31 shows a single horizontal turbine intended for placing in an open penstock. The water is delivered in a radial direction between the guide plates *a*, *a*; these plates are hinged and the amount of flow can be regulated by varying the opening between them. The opening or closing of the guide plates *a*, *a* is effected by turning the shaft *b*. The water is discharged from the wheel in an axial direction and passes through the casing *c* to the tail-race or draft tube.

**71.** Fig. 32 shows two horizontal turbines with closed penstock. The water is delivered through the pipes *a*, *a* to

the closed penstocks, or casings *b*, *b*, and having passed through the wheels is discharged into the draft tubes *c*, *c*. The governors *d*, *d* regulate the gate opening so as to keep the speed approximately constant.

**72. Draft Tubes.**—The draft tube is the discharge pipe leading from the turbine to the water level in the tailrace. The descending column of water in this tube creates a vacuum or suction (if all is tight against air leaks) and thereby makes the effective head of water acting on the wheel the same as if the wheel were placed at the level of the water in the tailrace, or it augments the power obtained over and above that

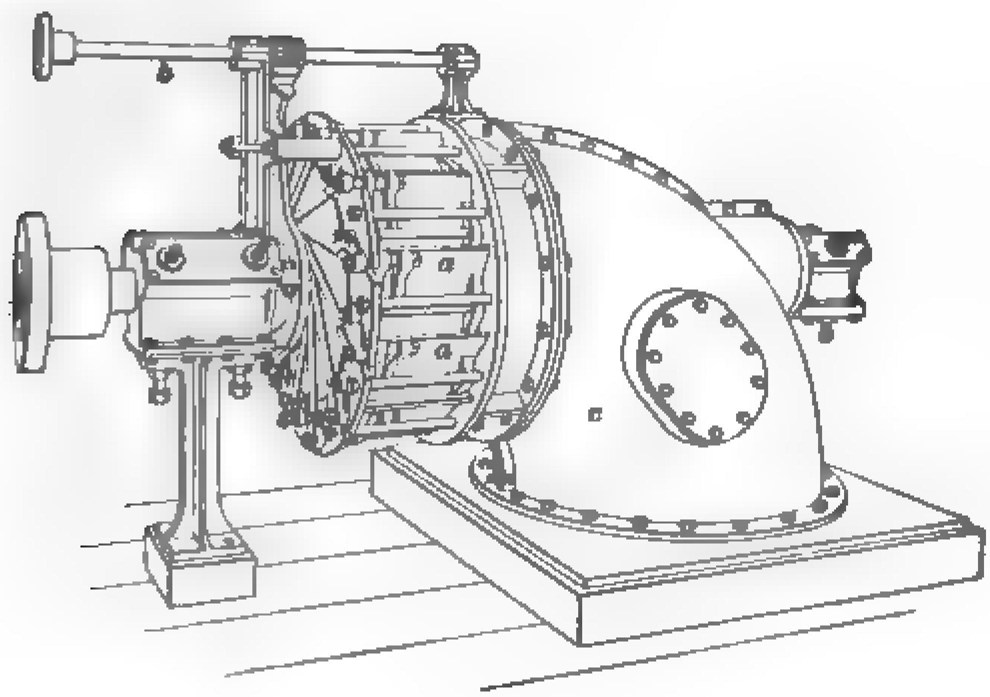


FIG. 31

which would be obtained if the wheel were placed above the lower water level and provided with an open discharge. In fact, the draft tube has a relation to the turbine wheel somewhat similar to that of a condenser to an engine. The end of the draft tube must, of course, always be below the surface of the water in the tailrace.

Theoretically, the turbine wheel with draft tube could be set at an elevation of 33 feet above the level of the water in the tailrace, the end of the draft tube being submerged sufficiently to prevent the air entering the tube, and thereby displacing the head-pressure, but practically, it is found

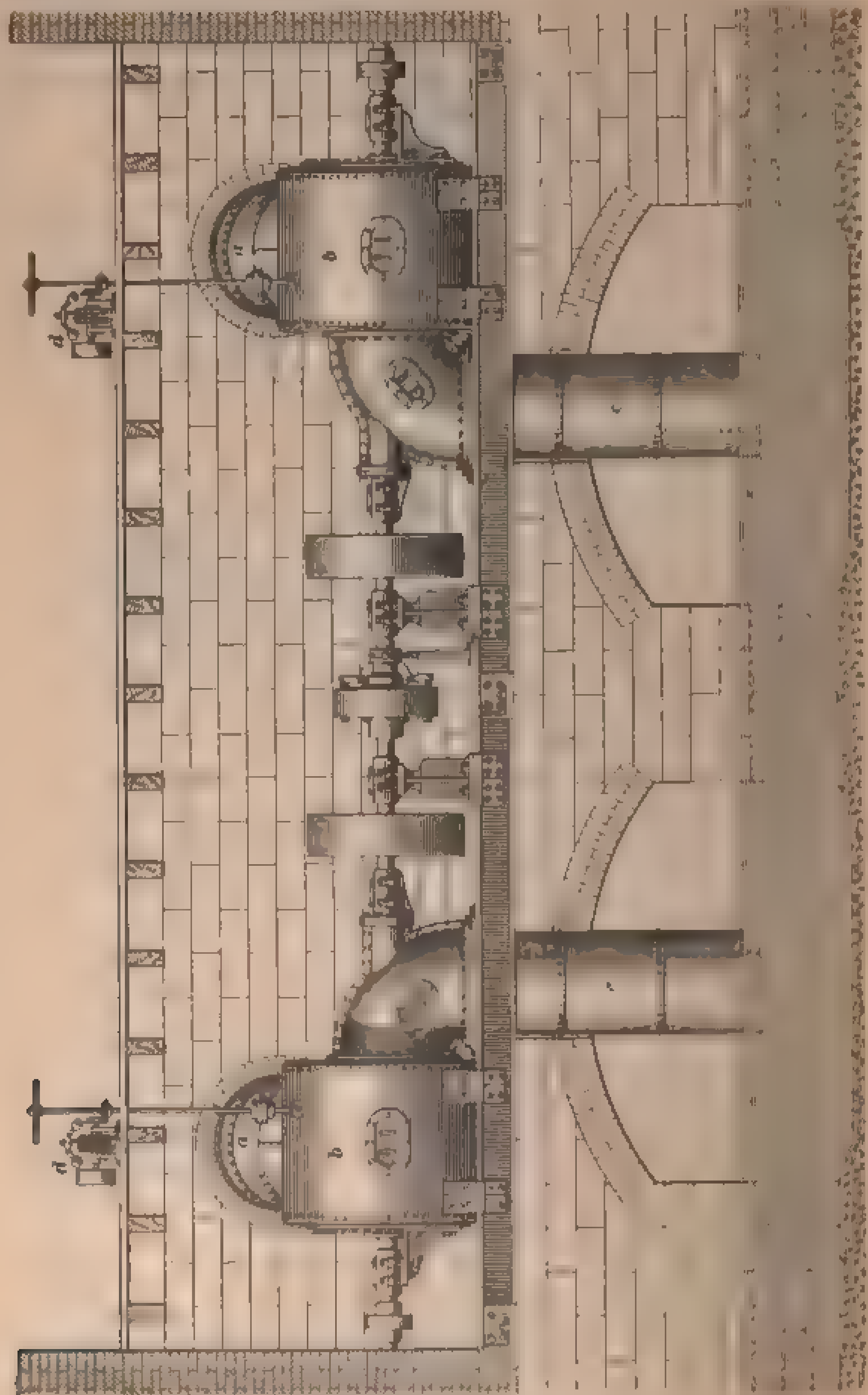


Fig. 82

desirable to set the wheels at an elevation not exceeding 18 feet above the level of the water in the tailrace.

**73. Relation Between Head and Discharge.**—With turbines of the same diameter and vent under different heads, the speed and discharge increases directly as the square root of the head. For example, if the head is made four times as great, the speed will be $\sqrt{4}$, or twice as great, and the wheel will discharge twice as much water per hour. The horsepower increases with the increase in head and also in proportion to the discharge. In the above case the head is increased fourfold and the amount of water discharged is doubled; hence, the horsepower will be eight times as great. A turbine that under 15 feet head gives 40 horsepower and vents 1,760 cubic feet at 160 revolutions per minute, should under 60 feet head, or an increase of four times, discharge $1,760 \times \sqrt{4} = 3,520$ cubic feet of water at 320 revolutions and develop eight times as much power, or 320 horsepower.

**74.** Turbine wheels are ordinarily used for heads of water ranging from 6 to 175 feet. For low and medium heads, wheels of ordinary weight and strength are sufficient, but for heads above 50 feet it is frequently necessary that the wheels shall be designed and built especially for each individual installation. It is desirable in applying turbines for electric power station work that they should be of the horizontal type and arranged as to speed and position in the station for direct connection to the shaft of the generator. It is extremely undesirable to introduce any intermediate pulleys, gearing, or belting, as the loss of power through such will vary from 10 to 30 per cent.

## EXAMPLES OF TURBINE INSTALLATIONS

**75.** Fig. 33 shows a typical arrangement of horizontal turbines direct-connected to alternators. This arrangement is for a low head and in order to avoid using a large number of small generating units, each generator is driven by four turbines *a*, *b*, *c*, *d*, mounted on a common shaft extending

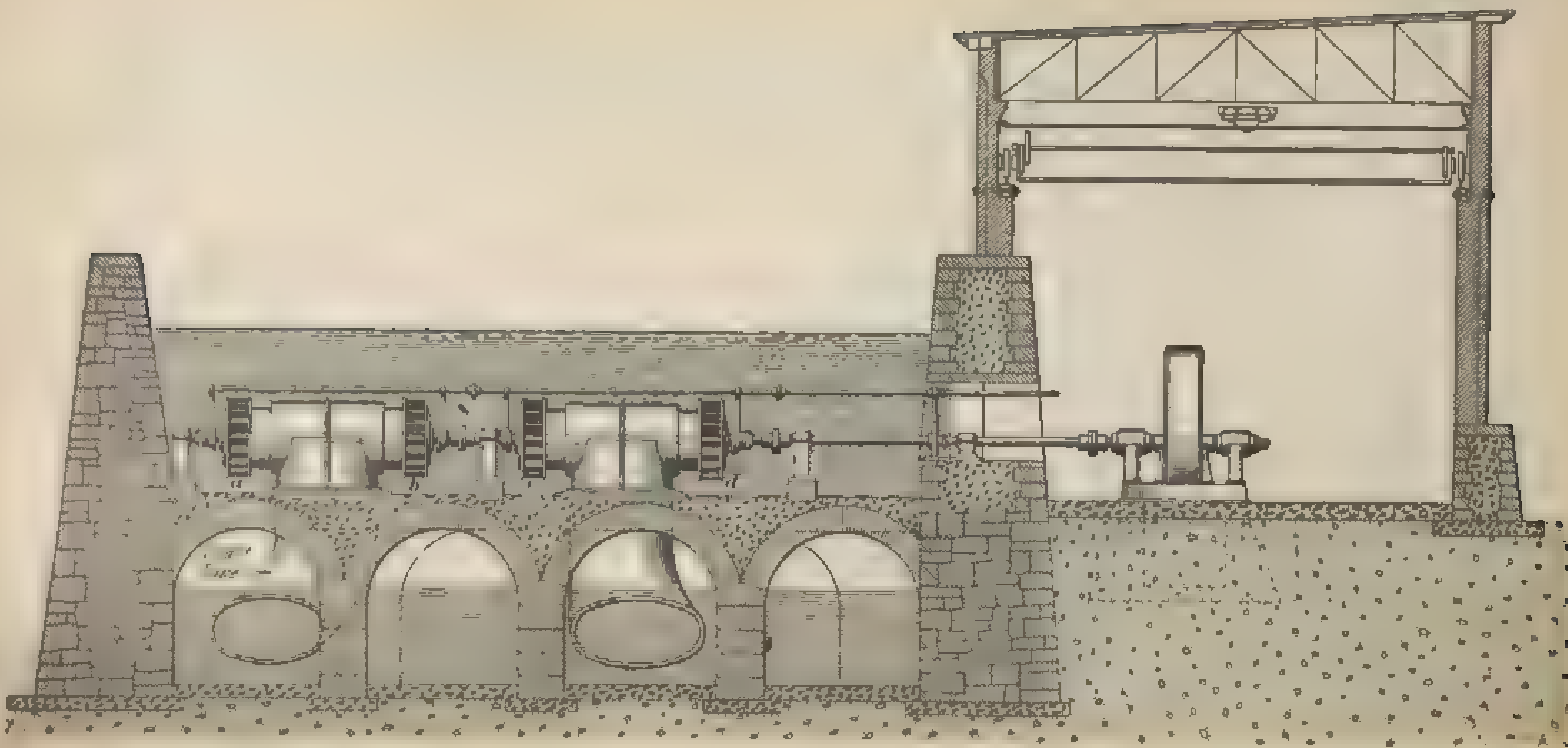


FIG 33

through the wall or bulkhead into the dynamo room. Fig. 34 shows a somewhat similar arrangement. The total head is 27 feet and there are three wheels coupled to each generator. The bottom of the wheel casing is 10 feet 3 inches above the level of the tail-water, and draft tubes are provided as shown.

**76.** Figs. 35, 36, and 37 show three views of a station equipped with horizontal turbines direct-connected to 400-kilowatt alternators and operating under 28 feet head. In

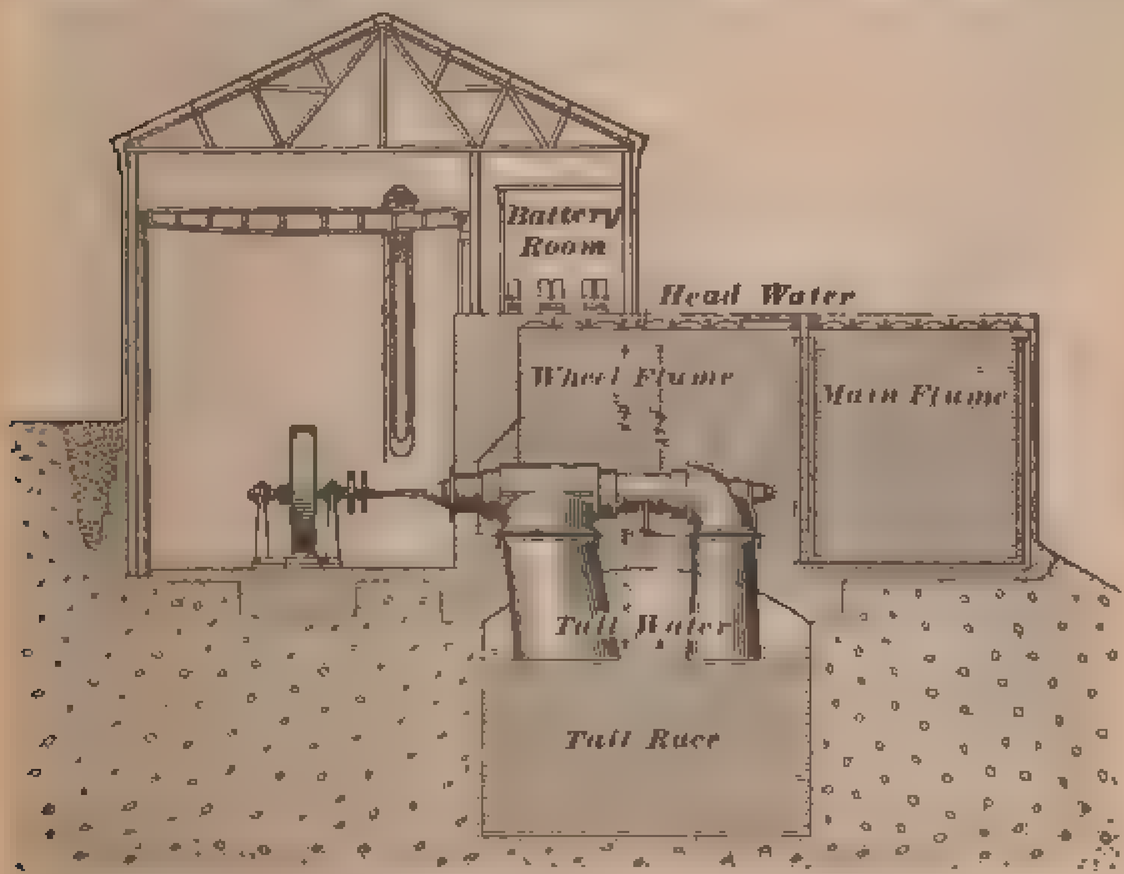
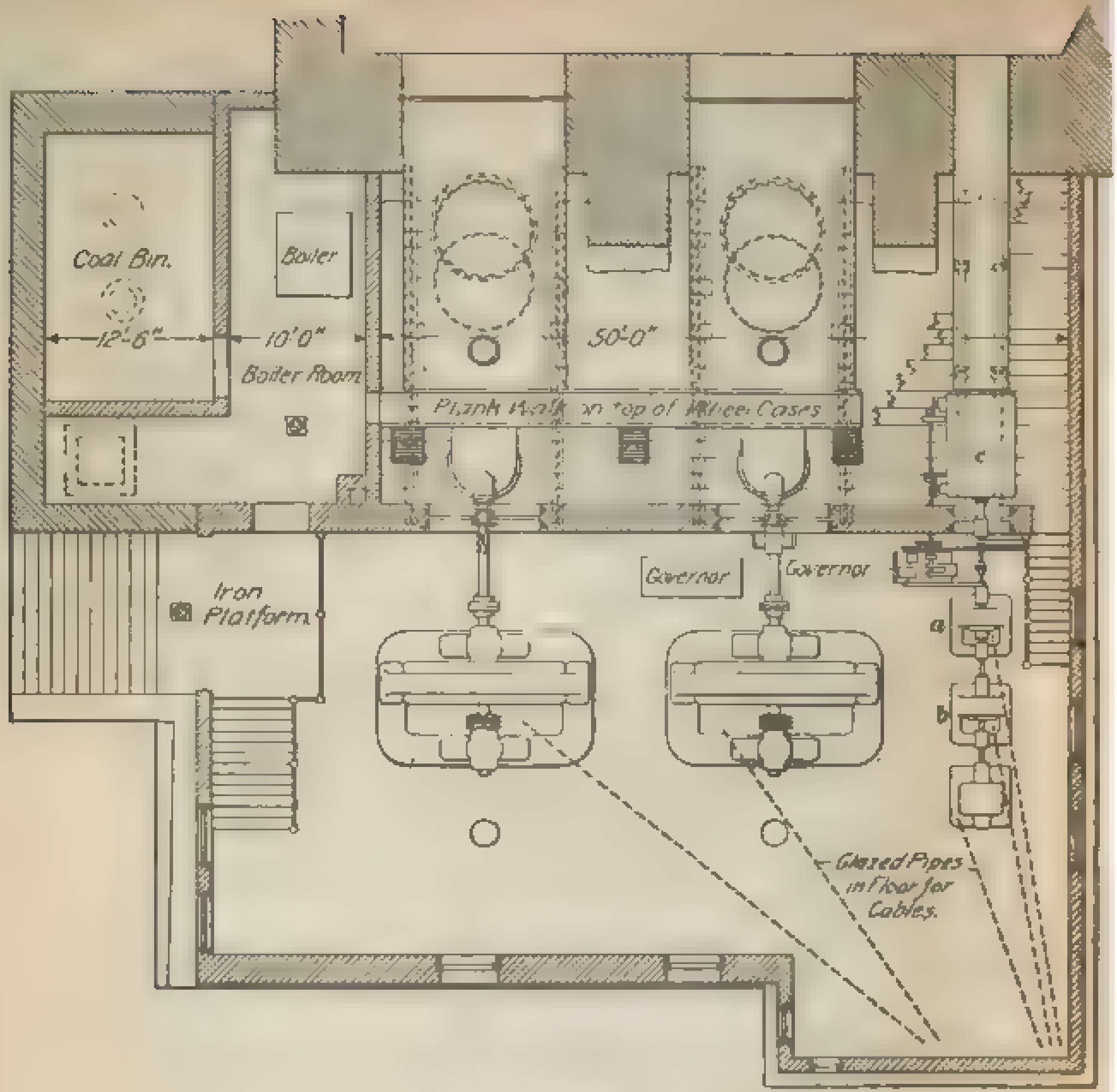


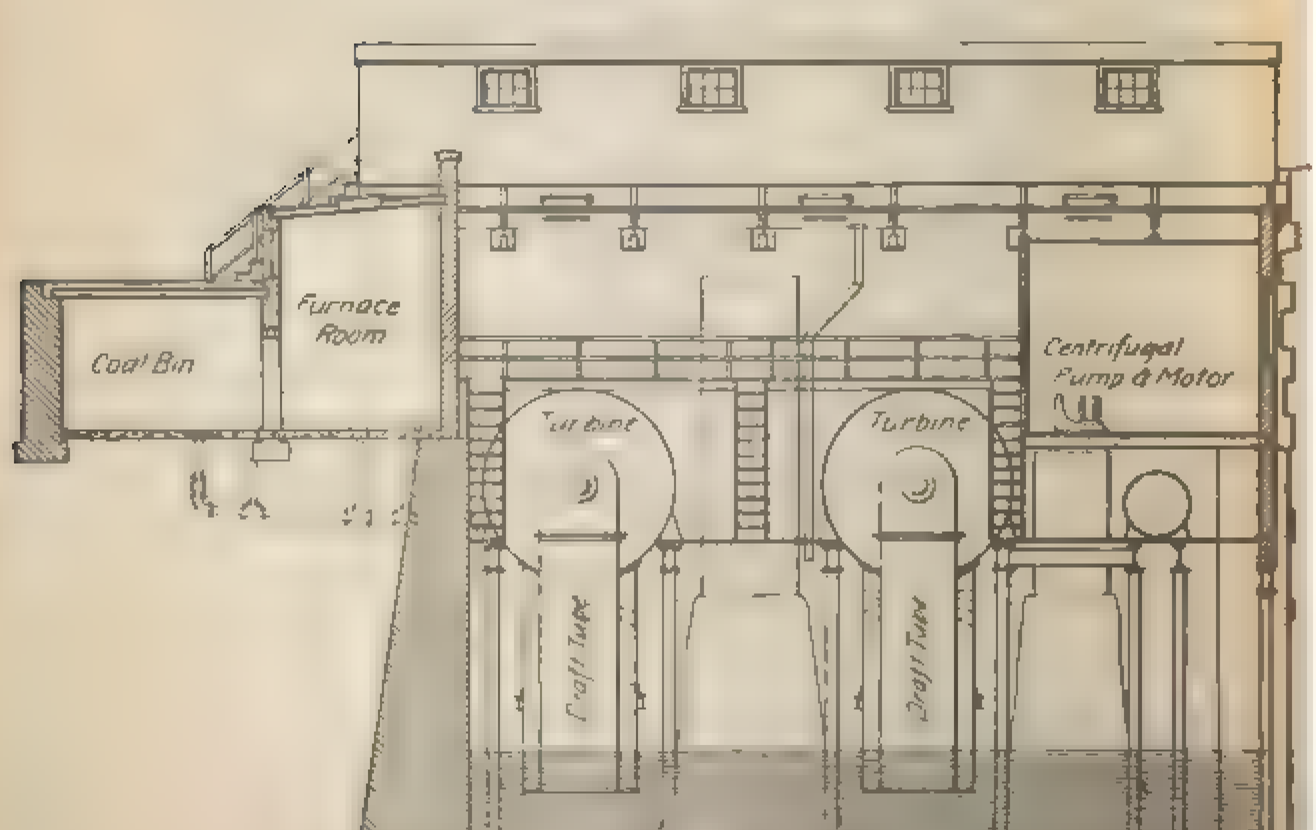

FIG. 34

this installation the wheels are encased in water-tight casings made of boiler plate and are placed in a wheel house. Water flows from the canal, through the end of the casing, and, passing through the turbines, flows through the draft tubes. The exciters *a*, *b* are driven by a small independent turbine *c*, so that their speed is constant irrespective of fluctuations in the speed of the main wheels, thus securing better voltage regulation than where the exciters are driven from the main wheels.



Coal Bin.
Boiler
12'-6"
10'0"
Boiler Room
50'0"
Plank Walk on top of Wheel Cases
Governor
Governor
Iron Platform
a
b
c
Glazed Pipes in Floor for Cables.


Fig. 35



Coal Bin
Furnace Room
Centrifugal Pump & Motor
Turbine
Turbine
Draft Tube
Draft Tube

**77.** As a prominent example of vertical turbine installation, the plant at Niagara Falls may be chosen. Fig. 38 shows a cross-section of the later power house and wheel pit. The

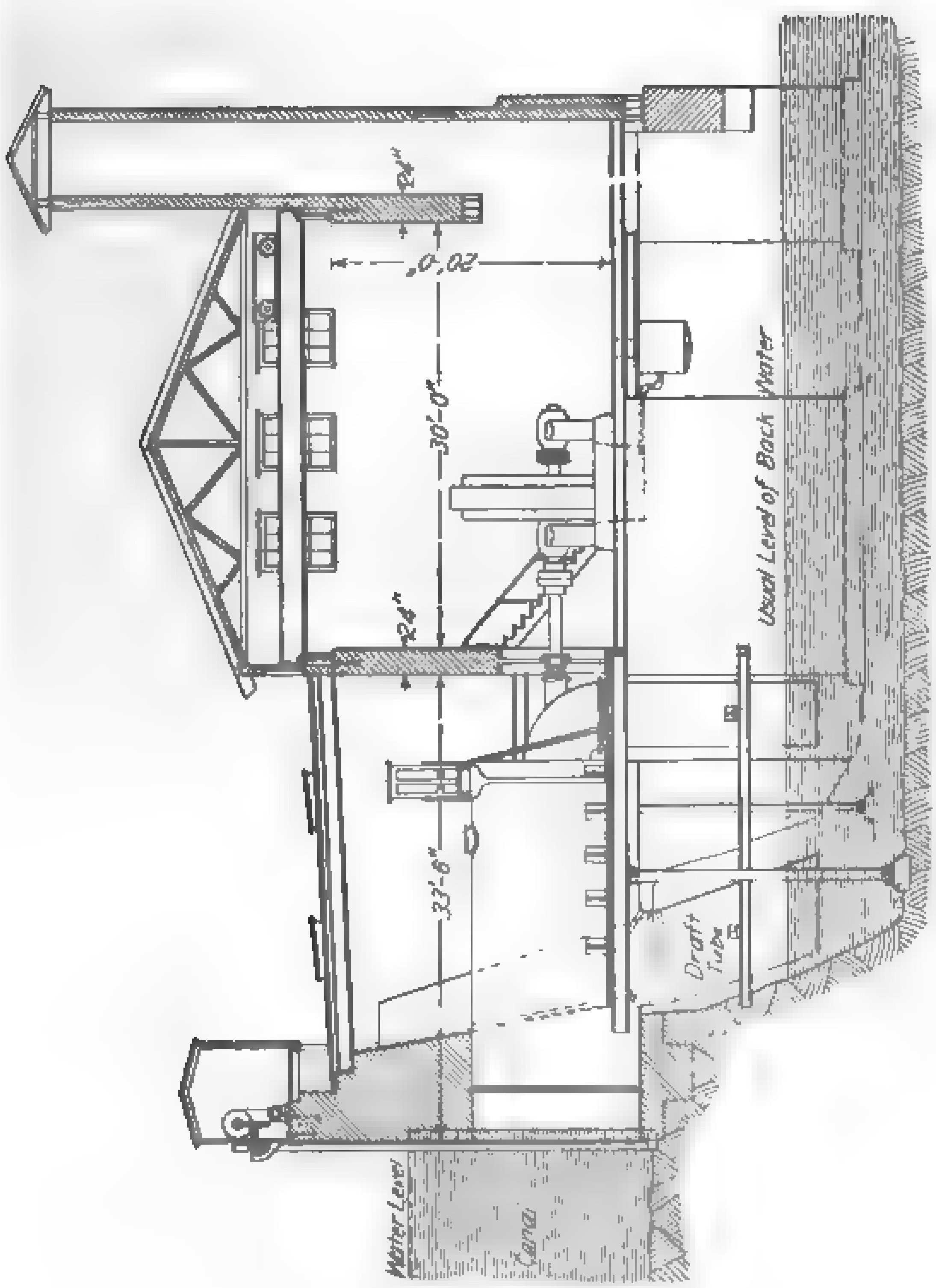



FIG 37

water is taken from the canal *a* and flows down the vertical penstock *b* to the wheel *c*; after passing through the wheels, it flows down through the draft tubes *d* and off through the tunnel at *e*. In the first installation at Niagara, draft tubes

FIG. [illegible]

were not used. The vertical shaft *f* is in the form of a large, hollow, steel tube, except at the bearings, and on its upper end carries the revolving field of the alternator *g*. The alternators are of 5,000 horsepower capacity at 250 revolutions per minute, two-phase, 25 cycles, and wound for 2,300 volts. In order to avoid long shafts, the independently driven exciters are located in an underground chamber and are driven by small wheels supplied from the main penstock. The head of water from the surface of the canal to the surface of the water in the tunnel is in the neighborhood of 160 feet.

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## IMPULSE WHEELS

**78.** Where water-power of any considerable head is obtained, say from 100 feet upwards, it frequently becomes desirable to use a type of wheel different from the turbine. A successful development in waterwheels for extra high heads is the *Pelton wheel*, which will serve as an example of **impulse wheels** in general.

**The Pelton wheel**, Fig. 39, consists of a series of peculiarly shaped buckets *a*, *a* mounted on the rim of a wheel. The buckets are wedge-shaped in the center for the purpose of dividing the stream and deflecting it backwards so as to develop its full force. While passing out from the bucket, the water sweeps against the curved sides and gives the effect of a prolonged impact. It is thus deflected to each side from the course of the wheel and offers no resistance to the rotary motion. In Fig. 39, the wheel is shown with the surrounding casing removed. In most electric

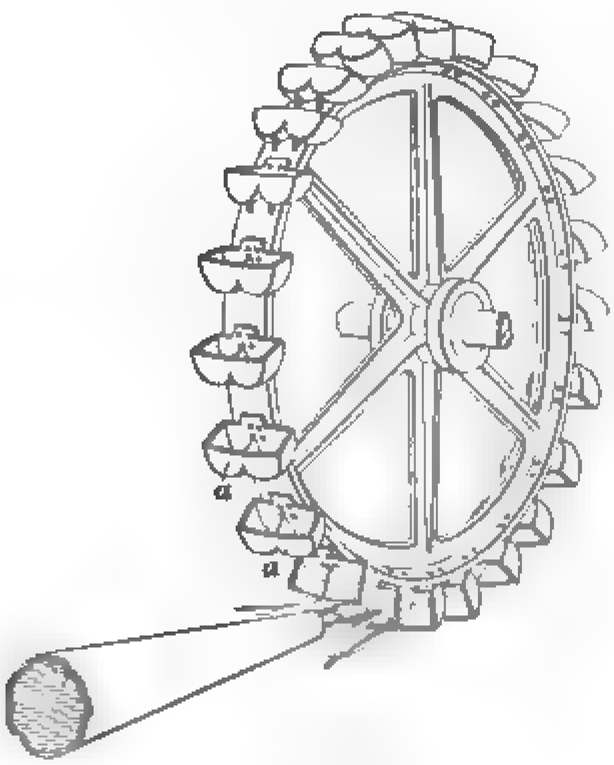
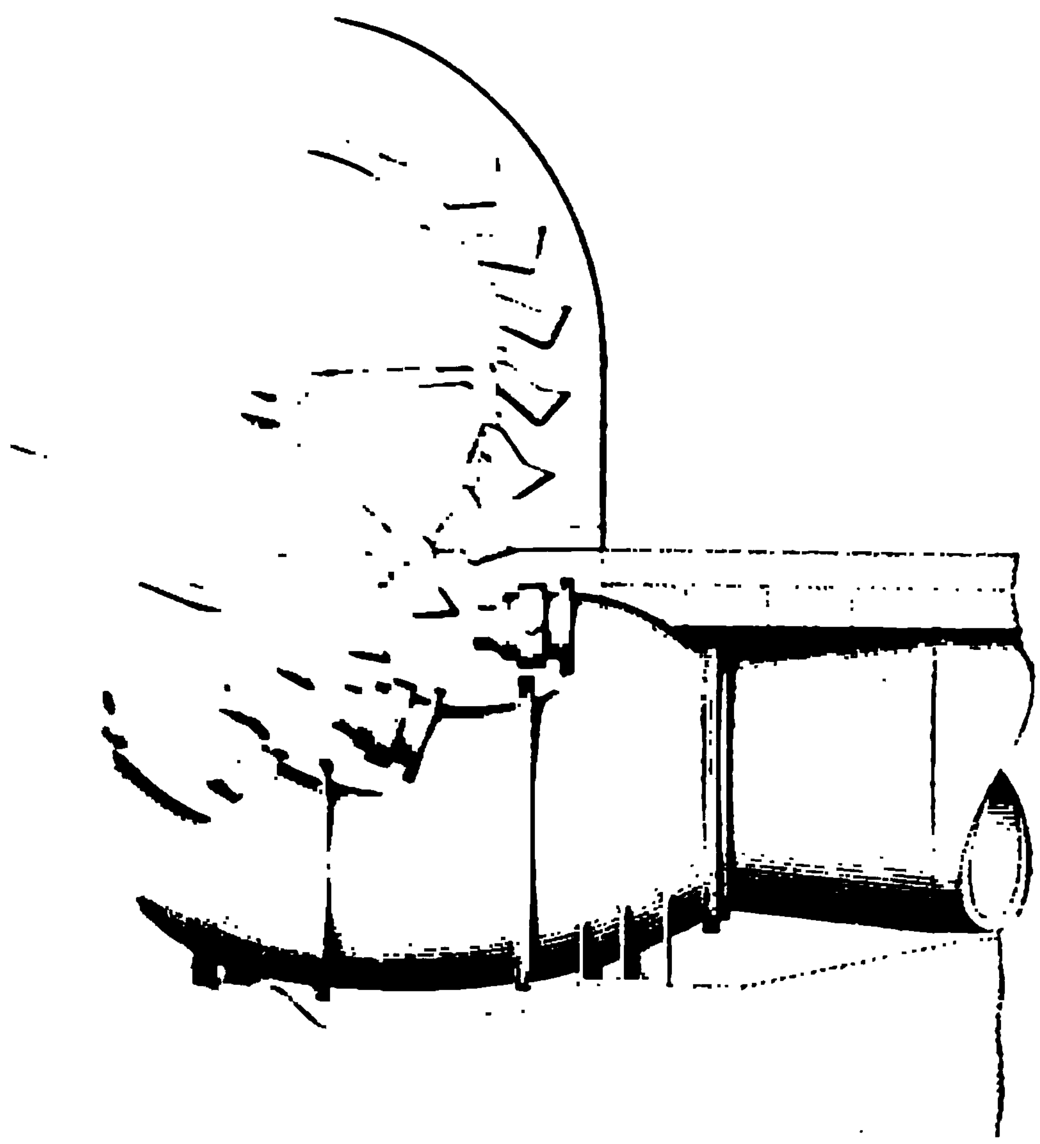


FIG. 39

... they are mounted
... an iron casing.
... with one or more
... of buckets being
... through which can
... matic regulation is
... suitable connections.
... governor. The wheel



... 10

... type and is particularly well
... generators. It is claimed that
... under favorable circumstances,
... 85 per cent.

... **Wheel for Low Heads.**—Fig. 10 illus-
... driven by water delivered through
... the streams have a distinct line of
... conflict and there is therefore no
... ency. By this means adaptation can

be made to almost any requirement as to power for heads ranging from 25 feet upwards. Each nozzle has an independent gate valve to facilitate regulation and adapt the wheel to varying supplies of water. Where automatic regulation is desired, the valves, by suitable connections, can be controlled by one governor.

Fig. 41 shows a Pelton wheel, with the top half of its casing removed, designed for dynamo driving and provided

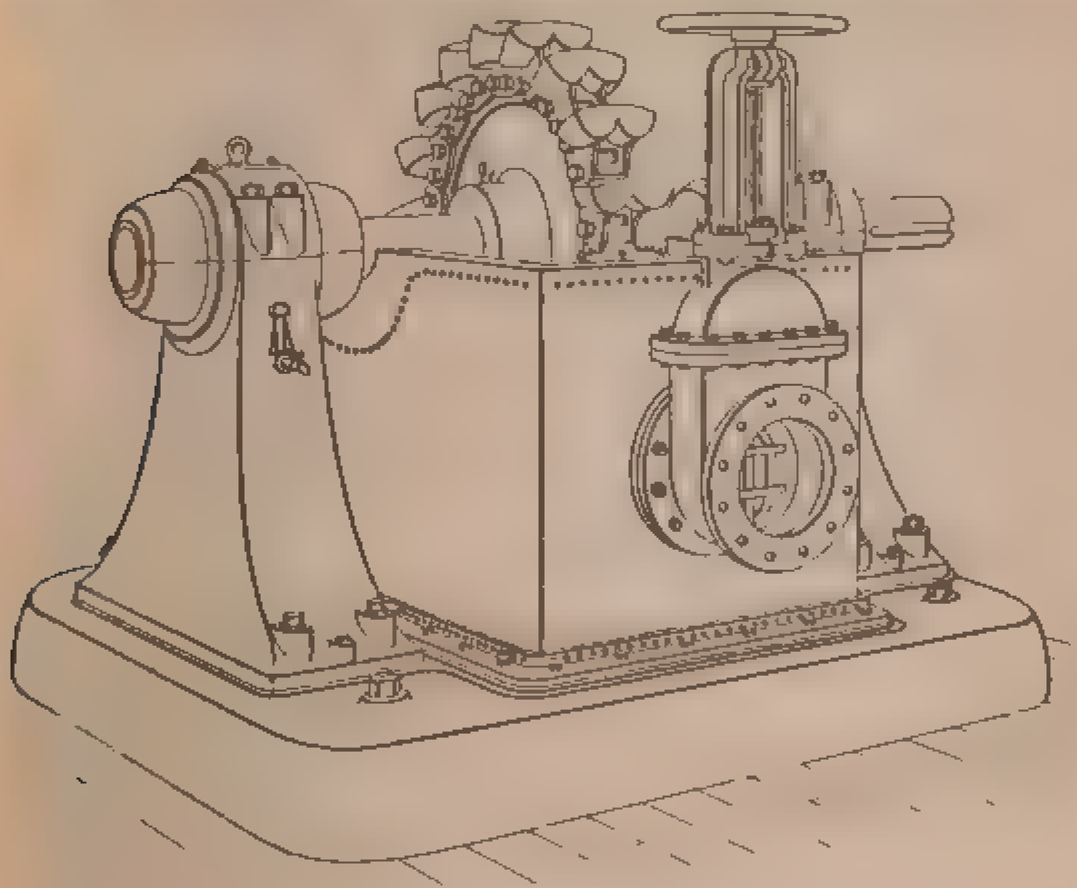


FIG. 41

with a base and self-oiling bearings of the same general style as used for dynamos.

The impulse wheel can be successfully used under vertical heads of water ranging from 25 feet to 2,500 feet, though its chief use lies in connection with heads over 100 feet. A remarkable installation has been made near Virginia City, Nev., where a wheel of 36 inches diameter and made of a solid steel disk with buckets riveted to the periphery, is used. This wheel operates under a vertical head of 2,100 feet of water equal to 911 pounds pressure per square inch. The

wheel runs at 1,150 revolutions per minute, giving a speed at the circumference of 10,804 feet per minute, or over 120 miles per hour. The water issues through a ½-inch nozzle and the wheel develops 100 horsepower.

### OPERATION OF IMPULSE WHEELS

**80.** The function of a waterwheel operated by a jet of water escaping from a nozzle is to convert the energy of the jet, due to its velocity, into useful work. In order to utilize this energy to the fullest extent, the shape of the wheel bucket must be such that, after receiving the jet, the water will be brought to rest before discharge. This, of course, cannot be fully effected, and unavoidably necessitates the loss of a portion of the energy. The principal losses occur as follows: First, in sharp or angular diversions of the jet in entering, or in its course through the bucket, causing impact, or in the conversion of a portion of the energy into heat instead of useful work; second, in the so-called frictional resistance offered to the motion of the water by the wetted surfaces of the buckets, causing also the conversion of a portion of the energy into heat instead of useful work; third, in the velocity of the water, as it leaves the bucket, representing energy that has not been converted into work. Hence, in seeking a high efficiency the following features must be provided for: First, the bucket surface at the entrance should be approximately parallel to the relative course of the jet and the bucket should be curved in such a manner as to avoid sharp, angular deflection of the stream. If, for example, a jet strikes the surface at an angle and is sharply deflected, a portion of the water is backed, the smoothness of the stream is disturbed, and there results considerable loss by impact and otherwise. The entrance and deflection of the water in the Pelton bucket are such as to avoid these losses in the main. Second, the number of buckets should be small, and the path of the jet in the bucket short; in other words, the total wetted surface should be small, as the loss by friction will be proportional to this.

Third, the discharge end of the bucket should be as nearly tangential to the wheel periphery as is compatible with the clearance of the bucket that follows, and great differences of velocity in the parts of the escaping water should be avoided.

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## WATERWHEEL GOVERNORS

**81.** For satisfactory service in water-driven electric power stations, uniformity of speed has required the development and application of types of **governors** designed on theoretically correct lines, and fully adapted to all the requirements of perfect regulation under sudden load variations. The governing of waterwheels for such service has been a difficult problem, and has required a complete revolution in the design of governors, which were previously suitable for manufacturing purposes only. The result has been accomplished to such a point of success that the regulation is equal to the best steam practice, and in some instances, particularly for generators of the alternating-current type, is eminently satisfactory. Less difficulty is experienced in running waterwheel-driven alternators in parallel than those driven with reciprocating engines.

In connection with waterwheel regulation, the difficulty has been to produce a governor that would accomplish the required results without allowing the wheel to race or hunt. Most of the earlier types consisted of a flyball governor, similar to that used on a steam engine, arranged so as to control the opening and closing of the gates. When the speed rises above normal, the balls fly out, thus throwing into action the appliances necessary for closing the gate If the speed falls below normal, a reverse action opens the gates. With this type of governor, if the load is, say, suddenly reduced, the balls fly out beyond their normal position and the gate opening is reduced. Owing, however, to the inertia of the various parts, the speed does not drop at once and before the speed has come back to its normal amount, and the governor balls assumed their normal position, the gates have been closed too much and the speed

drops below the normal. In other words, the regulation overshoots the mark and there is a seesawing or hunting action until the speed finally settles down to the normal. This hunting or racing action is not so objectionable where the wheels are used to run ordinary machinery, but it cannot be tolerated where the wheels are used to drive alternators. In a number of the more recent types of governor the effects of inertia and consequent hunting are overcome. There are a number of successful types of governor on the market, but for purposes of illustration we will select the *Lombard governor*, which has been widely and successfully used in electric water-power plants where the waterwheels are direct-connected to alternators and where the requirements as to speed regulation are, therefore, very exacting.

## LOMBARD GOVERNOR

**82.** In the **Lombard governor**, Fig. 42, the movement of the gate is effected by means of the oil or water pressure acting on a piston, and the admission of oil or water to the operating cylinder is controlled by a centrifugal governor, the action of which is modified by the gate movement in such a manner as to compensate for the effects of inertia. Water pressure is used for moving the gates only in those cases where the wheels are operated under high heads and where a high water pressure is thus easily obtained. Most of the Lombard governors are operated with oil pressure; that shown in Fig. 42 is known as the *Type B governor*, and is the kind used for most installations operating under low or moderate heads.

**83.** In Fig. 42, the oil used for operating the governor is stored in the tank located under the governor. This tank is divided by an air-tight partition into two compartments *1*, *2*; compartment *1* is smaller than *2*, the partition being at the point indicated by the row of rivet heads. The larger compartment is partly filled with thin, petroleum, engine oil and over this oil is air under a pressure of about 200 pounds per square inch. A vacuum is maintained in compartment *1* and

air is compressed into *2* by means of a pump *3* driven by a pulley *1* belted to the waterwheel shaft. Gauges *5* and *6* indicate the pressure and vacuum, respectively. A pipe *7* leads from the oil in *2* to the oil-filled valve *8*, which is opened or closed by the centrifugal governor *9*. This governor is belted to the waterwheel by means of pulley *10*. A

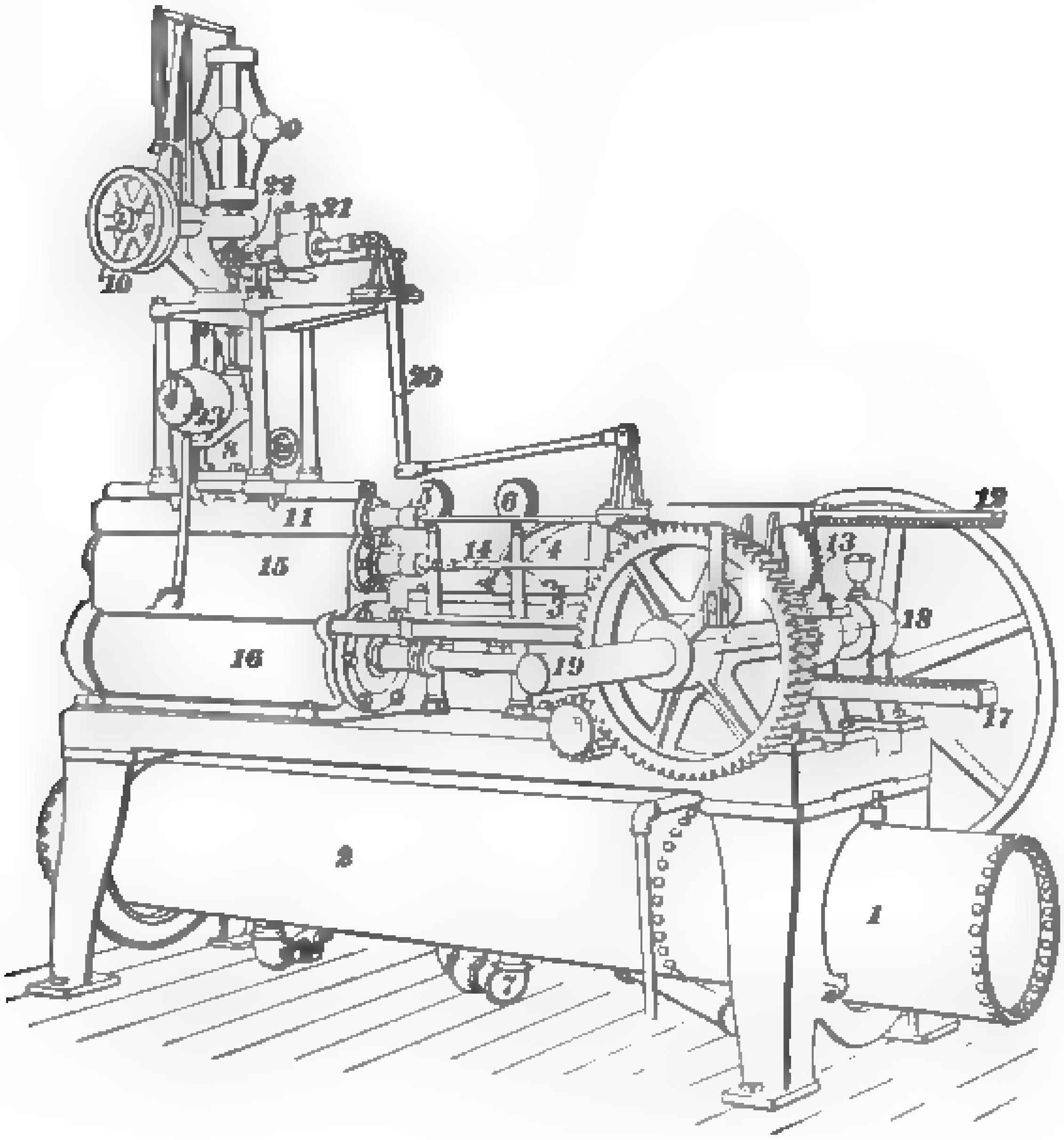


FIG. 42

small, balanced, piston valve located at *8* allows oil under tank pressure to flow into either end of the small horizontal cylinder *11*. The piston and piston rod in this cylinder terminate in a rack *12* that runs on top of a floating gear *13*. This gear has no fixed center, but to its axis is attached the piston rod *14* that actuates a large piston valve in cylinder *15*.

This valve, according to its position, allows oil to flow into either end of the largest cylinder *16* in which is a piston attached, through its piston rod, to the large rack *17*. This rack engages with a gear *18* on shaft *19*, which is connected to the gate-operating mechanism of the wheels. One complete inward stroke of the main piston and rack closes the gates, while a complete outward stroke gives a full-gate opening. When the wheel is running at normal speed, valve *8* occupies a neutral position and there is no movement of the governor. Suppose that part of the load on the wheel goes off suddenly. The speed will immediately begin to accelerate and the balls of the governor *9* will fly out, thus depressing the valve at *8*. This admits oil into the rack end of cylinder *11* and its piston travels inwards, carrying with it rack *12*; the floating gear *13* that meshes with *12* also travels inwards, carrying with it the rod *14* and opening the valve in *15*. This admits oil to the front end of the cylinder *16* and allows it to flow out of the back end, thereby moving rack *17* inwards. Now, as soon as rack *17* moves inwards, it turns gear *19* and this in turn rolls the floating gear outwards, thus bringing the valve in cylinder *15* to its central position. This stops all motions of the governor and the gates are at the correct position for the new value of the load.

The above actions have been described as occurring consecutively, but as a matter of fact they occur so rapidly, one after the other, that the action appears almost simultaneous. The oil discharged from cylinders *11*, *15*, and *16* is returned to the vacuum tank *1* from which it is returned to tank *2* by means of pump *3*. It will be noted that no air circulates through the cylinder of the governor. The compressed air on top of the oil in tank *2* acts simply as a reservoir of energy, which is instantly available for the operation of the governor. If the load on the wheels suddenly increases, all the various motions above described are reversed.

**84.** The governor as above described would not give satisfactory regulation. Whenever piston valve *8* is moved out of its normal position by variations in the speed of the

balls, it would remain out of position until the balls came back to their normal position. All the while that valve *8* is out of its central position, the main piston and rack will be traveling in one direction or the other. As before stated, the centrifugal balls do not respond instantly to change in speed and the result is that the governor overshoots the mark. In the Lombard governor this defect is overcome by an attachment that centralizes valve *8* before the time that it would be centralized by the balls coming back to the normal position. This auxiliary movement of the valve stem is controlled by the gate movement through the lever *20* attached to rack *12*. Lever *20*, through dashpot *21*, operates a small rack and pinion *22* by means of which the valve stem of valve *8* is raised or lowered independently of the movement due to the balls, and the movements of valve *8* are thus regulated so that by the time the balls resume their normal position, the gate opening is such that the wheel runs at the proper speed and there is no hunting or seesawing. In order to allow the speed of the wheel to be regulated from a distant point, for example, from the switchboard, a small motor *23* is geared to the valve stem of valve *8*; this motor is reversible so that the stem can be raised or lowered at will when it is necessary to adjust the speed. This attachment is particularly convenient when alternators are to be synchronized.

## REQUIREMENTS FOR GENERAL POWER-STATION BUILDINGS

**85.** In conclusion, it may be stated that the design of power-station buildings and the arrangement of apparatus therein admit of wide variation. No set rules can well be laid down to govern all classes of work. The capacity of the station, the types of equipment selected, and the environment of the plant will all have a bearing thereon.

There are, however, certain leading points that should always be kept in mind, and these may be summed up as follows:

(*a*) Substantial foundations.

(*b*) A fireproof building.

(*c*) Ample working space around all apparatus.

(*d*) Such a convenient arrangement of apparatus as will require the minimum of labor for its proper attendance.

(*e*) Doorways of ample width and height to admit of taking in and getting out the largest pieces of equipment

(*f*) In front of boilers, ample space to withdraw and replace tubes.

(*g*) Around engines, ample space to take out pistons, remove and replace shafts, wheels, generators, etc.

(*h*) In engine rooms, a traveling crane or other suitable means for handling heavy parts with safety and minimum of labor.

(*i*) Ample facilities for light and good ventilation.

(*j*) Suitable lavatory accommodations for employes, according to sanitary rules.

(*k*) Such design of buildings and placing of apparatus as will admit of future extensions without destroying existing plant or interfering with its operation.

(*l*) Avoid architectural monstrosities, to the end that the character of the finished building may show the purpose for which it was designed.

# ELECTRIC-RAILWAY SYSTEMS

## METHODS OF SUPPLYING CURRENT

**1.** Electricity is now generally conceded to be the most economical power for the operation of street railways. It has shown itself superior to horses, compressed air, or cable, both as regards flexibility and cheapness of operation. Cable roads may be advantageous in some very hilly localities; but for ordinary traffic, most of the cable roads installed some years ago have been converted into electric lines. Compressed air has been used in a few cases, notably in mining work, but for general purposes electricity has the field practically to itself.

**2.** So far, electric cars have been operated by direct current almost exclusively; that is, the current supplied to the cars is direct though the current supplied from the station may be alternating. On roads where a considerable amount of power has to be transmitted a long distance, alternating current is used in order that the transmission may be carried out economically at high line pressure, but even under such circumstances the general practice has been to step-down the alternating current and transform it to direct current before supplying it to the cars. On roads where the distance of transmission is not very long, direct current may be supplied from the station and the use of alternating current is unnecessary; if boosters are used, as described later, the radius of direct-current supply can be extended considerably.

The direct-current series motor is admirably adapted for traction work, and alternating current has not been used to

any extent on the cars for the reason that heretofore no alternating-current motor that could compete on all points with the direct-current motor has been available. A number of roads are operating in Europe on which polyphase induction motors are used, but the induction motor has never been used to any extent in America because it presents a number of disadvantages. It is essentially a constant-speed motor and is not well adapted for work where a variable speed, large starting torque, and decreasing torque with increasing speed are desired. Again, three-phase motors necessitate at least two trolley wires. However, it has long been recognized that the use of alternating-current motors on cars would simplify and cheapen the construction of roads on which alternating current must be used for the transmission of power. Rotary converters are dispensed with and it becomes possible to use a much higher pressure between the trolley wire and the rail. Within the last few years, a great deal of experimenting has been done on the use of single-phase motors for traction work, and it is probable that this type of motor will be largely used for interurban roads. A single-phase motor requires only one trolley wire, and the motors so far developed have speed and torque characteristics very similar to those of the direct-current series motor. It is safe to say, therefore, that in many future installations alternating current will be supplied to the cars and rotary-converter substations dispensed with on those roads where the conditions are such that direct current cannot be used economically for the transmission from the station.

## VOLTAGE

**3.** The **voltage** at which current is supplied to the cars has in the past been limited principally by the conditions for sparkless commutation on the motors and also by considerations of safety. It is difficult to build direct-current motors that will operate without sparking or flashing under the severe conditions incidental to electric traction, if the pressure is over 650 volts. Also, in places where the trolley wire is

exposed, as in public streets or along public highways, the pressure should not be much over 500 volts on account of the danger to life. Thus, the general practice has been to use from 500 to 550 volts for city traffic and 600 to 650 volts for interurban traffic. Under conditions of heavy load, the pressure may be very much lower than these figures because of the large line drop. On interurban lines operating on a private right of way, there is no reason why a pressure higher than 650 volts could not be used between the trolley wire and track, provided that motors could be made to operate satisfactorily on the higher pressure. Experiments have shown that there is no special difficulty in collecting current at high pressure from an overhead trolley, though, of course, the wire has to be insulated better than is usual for ordinary 500-volt work. On the Berlin-Zossen experimental three-phase road, a trolley pressure of 10,000 volts was used without difficulty. With alternating-current motors, the current can be supplied at high pressure and stepped-down by means of a transformer carried on the car. The use of alternating-current motors will therefore in all probability be accompanied by trolley-wire pressures much higher than those customary with direct current, and a corresponding saving in the amount of copper required to supply current to the cars will be effected. The use of high trolley pressures will, of course, be confined to roads operating in places where the trolley wire will not be a source of danger.

## METHODS OF CURRENT COLLECTION

**4.** Several methods are available for supplying current to the cars, but the one to be used in any given case is generally fixed by local conditions. The usual methods are given below in the order of the extent of their application.

1. By means of an overhead conductor or pair of conductors connected to the car by an under-running contact; this is known as the *overhead-trolley system*.

2. By means of contact or conductor rails run alongside of, or between, the car rails, contact being made with the

car by means of sliding shoes; this is usually called the *third-rail system.*

3. By means of underground conductors run in a conduit and connected with the car by means of a contact plow passing up through a slot; this is called the *open-conduit system*, or *slot system.*

4. By means of electromagnetic switching devices that make connection between the car and a conductor situated underground; this is usually called the *electromagnetic*, or *surface-contact, system.*

5. By means of storage batteries carried on the car; in this case no conductors between the power station and cars are necessary.

It will aid in understanding the various methods of railway power distribution to consider, very briefly, the main features involved in each method. The details will be taken up later in connection with line and track construction.

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## OVERHEAD-TROLLEY SYSTEM

**5.** The **overhead-trolley system** is more widely used than any of the others. For lines in towns or cities, when a road is run along a public right of way and where the live working conductor must be placed so that there will be no danger of accidental contact with it, the overhead-trolley system is the cheapest both as regards first cost and cost of maintenance.

Fig. 1 shows a simple trolley system supplied from a direct-current generator. The positive terminal of the generator connects, through the switchboard, to the overhead-trolley wire; the negative terminal connects to the rail, and the path of the current is indicated by the arrows. The current is carried to the moving car by means of the under-running trolley wheel. This arrangement, simple as it may seem, was not arrived at without considerable experimenting. In the early electric roads two trolley wires were used, and the track was not employed as one side of the circuit. This scheme is still used in a few

places, notably in Cincinnati. Also, on the first roads installed, the trolley wheel ran on top of the wire; but this method of collecting the current was soon superseded by the under-running trolley.

It should also be noted that the cars are operated in parallel. This is true of all systems of distribution where current is supplied to the cars from an outside source. All street-railway systems are, therefore, operated at approximately constant potential; i.e., constant or nearly constant pressure is maintained between the trolley wire and the track. Wherever connection is made from the trolley to the track through the motors, a current flows and the car is propelled.

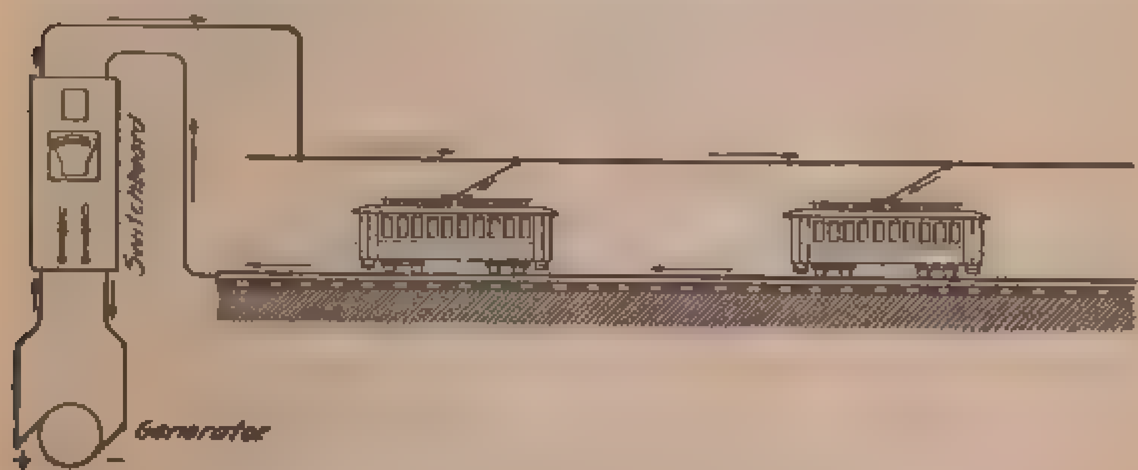


FIG. 1

Each car is independent of the others and takes an amount of current proportional to the power required to drive it.

The arrangement shown in Fig. 1 admits of many modifications. For example, except on very small roads, the trolley wire is not sufficiently large to carry the current necessary; so **feeders**, or heavy cables, are run to the station instead of carrying back the trolley wire itself. Also, in some cases, return cables are used in connection with the track. The overhead-trolley method is, at present, the only one that is available for the supply of current at high trolley pressures, the insulation provided by the other methods not being sufficient, to say nothing of danger from shock.

## THIRD-RAIL SYSTEM

**6.** The **third-rail system** is, in principle, the same as the overhead trolley. The trolley wire is replaced by a third rail mounted on insulators to one side of the track, or between the tracks on double-track roads, and slightly above the other rails. Current is supplied to the car by means of shoes that slide on the contact rail and the current returns through the track rails, as in the overhead system. In a few special cases, two conductor rails have been used, the track not being employed to carry the return current.

Fig. 2 shows the arrangement of collecting shoe for an ordinary third-rail equipment. The third rail *a a* is of the standard **T** pattern and is supported on insulators *b* resting on every fifth tie, which is extended for this purpose. The cast-iron shoe *c* is suspended from links, so that it is free to move up and down through a limited range, and the whole collecting device is attached to a wooden beam *d* carried by the truck. Cable *e* leads to the controlling devices on the car and connection is made to the shoe by means of bare flexible copper cable or braid *f*, the links not being depended on to carry the current. In some cases, a copper fuse is placed at *g* to cut off the current in case of short circuits.

The third rail is much used for roads where the traffic is heavy and when the presence of the contact rail does not interfere with other traffic. It is the outcome of a demand for a construction more substantial than the overhead trolley and better adapted to high-speed work and the collection of large currents. The contact rail provides a working conductor of large cross-section and long stretches of track can be supplied with current without any feeder other than the third rail.

**7.** A No. 000 trolley wire has a cross-section of .132 square inch; a 70-pound rail has a cross-section of about 7 square inches. Taking the conductivity of the conductor rail as one-tenth that of copper, the rail will be equivalent to .7 square inch of copper, or 5.3 times the cross-section of the trolley wire. If especially soft steel were used for the

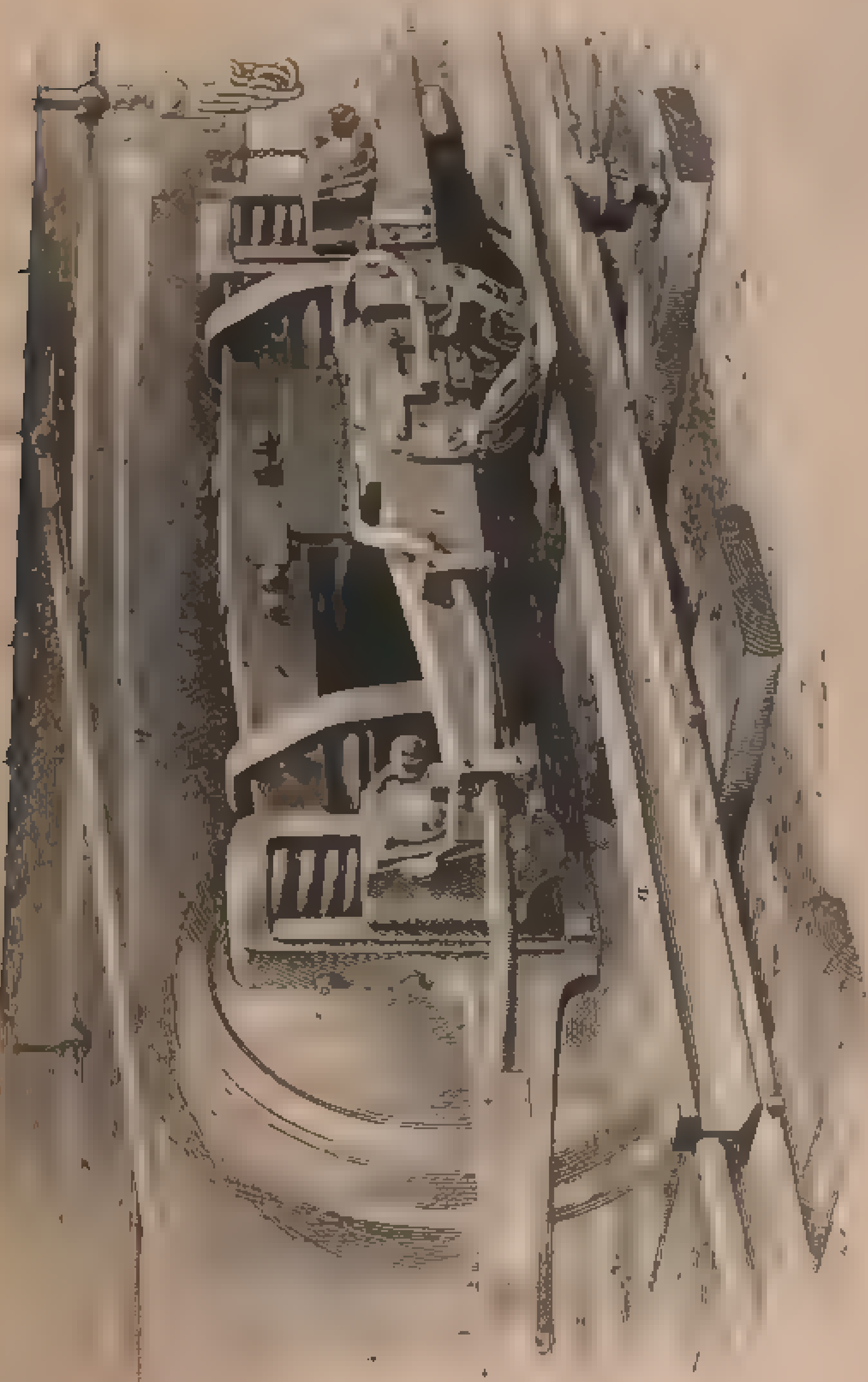

FIG. 2

third rail, the resistance might not exceed 7 to 8 times that of copper; but even with steel not especially made for high conductivity, a 60- or 70-pound rail will provide a much larger carrying capacity than a trolley wire of the size ordinarily installed. The third-rail construction is generally considered more expensive than the overhead trolley, but as a matter of fact it is cheaper when the comparison is made on a basis of equal current-carrying capacity.

**8.** This system is not without its disadvantages, and by some engineers it is thought that it will eventually give way to some kind of overhead construction more substantial than the ordinary trolley wire, or to some well-developed surface-contact system. There is unquestionably an element of danger in the exposed third rail even when the road is elevated, underground, or run on a private right of way carefully fenced in. The exposed live rail is in the way when track repairs are being made, though the trackmen soon become accustomed to it and accidents are surprisingly few. It is also very difficult to use it in yards and terminals, the numerous crossings of the tracks making the work very complicated and dangerous. On this account, on some third-rail roads the cars are equipped with overhead trolleys and all switching in the yards and at terminals is carried out by the overhead system.

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### OPEN-CONDUIT SYSTEM

**9.** The **open-conduit system**, because of the great expense of installation, is used only in a few large cities where the traffic is heavy enough to warrant the expense and where the city authorities do not permit the stringing of overhead-trolley wires and feeders. Current is supplied from two conductor rails placed in a conduit between the track rails. This conduit is closed at the top with the exception of a slot about $\frac{5}{8}$ inch wide, through which a plow suspended from the car passes. Two cast-iron shoes, carried by the plow, press sidewise against the conductor rails, and cables lead from the shoes to the motors on the

car. Fig. 3 illustrates the main features and Fig. 4 shows the arrangement of the plow in relation to the conductor rails. The conduit is made sufficiently deep so that mud and water will not interfere with the conductor rails, and at regular intervals sewer connections are provided. The two contact shoes *s*, *s* are pressed sidewise against the conductor rails *a*, *a* by flat springs *b*, *b*. Shoes *s*, *s* connect to cables *c*, *c*, which lead to the motors and controlling devices on the

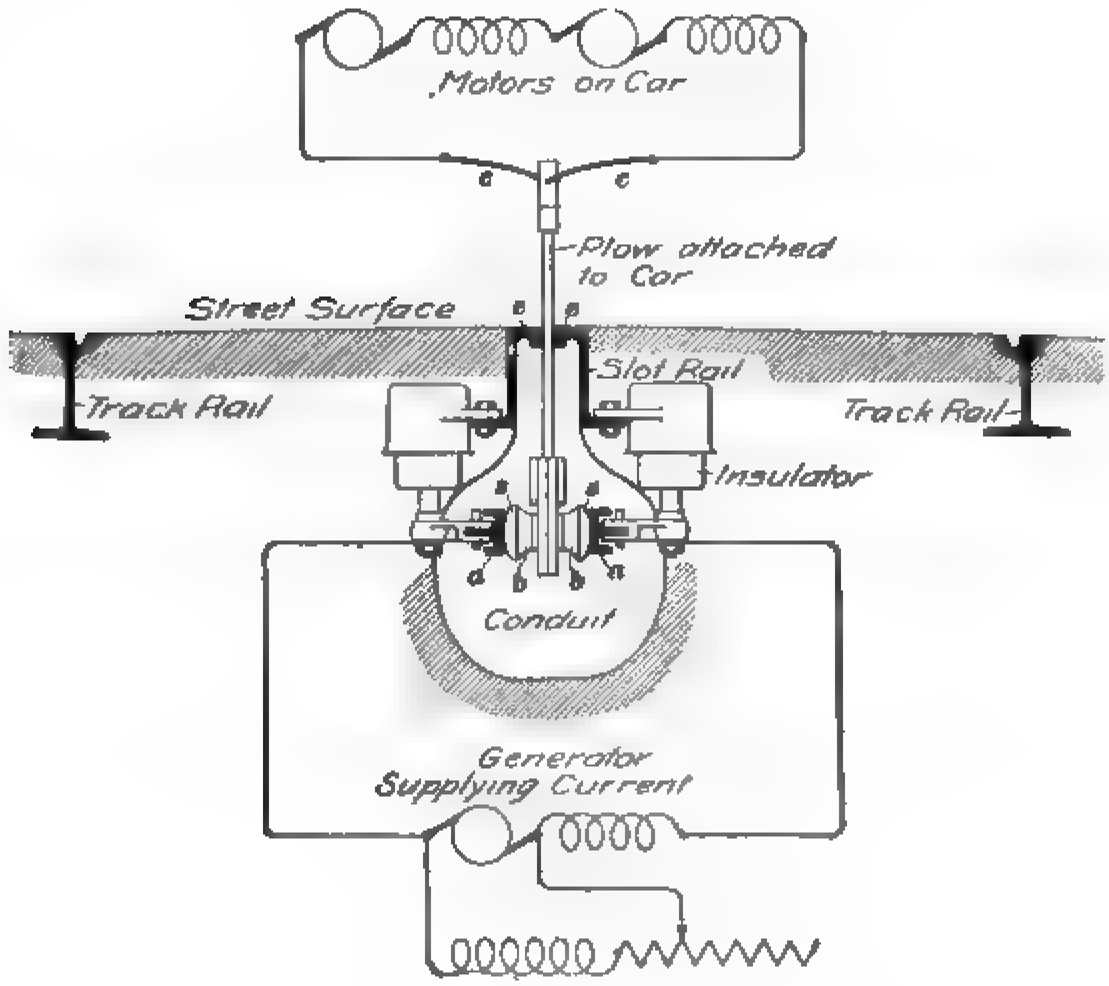


FIG. 3

car. The conductor rails *a*, *a* are connected to the power station by outgoing and return feeders run in ducts alongside the track. The part of the plow that passes between the slot rails *e*, *e* is made of steel plates riveted together, while tempered-steel wearing plates are fastened on the plow at the points where rubbing against the slot rails occurs.

While this system works satisfactorily if the conduit is kept properly cleaned, and avoids the use of overhead

conductors, it is not a generally applicable method. The cost of construction is from four to five times that of an overhead-trolley line, and it is only on roads having a dense traffic that it can be made to pay. The construction of the conduit in cities usually necessitates the removal or rearrangement of underground pipes, sewers, electric conduits, etc. that may lie in the path of the conduit, all of which increases the cost greatly.

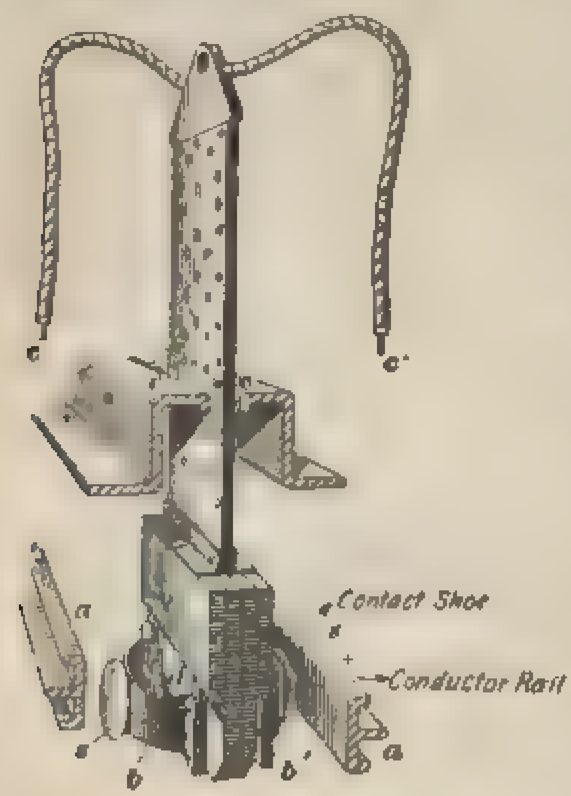


FIG. 4

## ELECTROMAGNETIC, OR SURFACE-CONTACT, SYSTEMS

**10. Surface-contact systems** have not been used to any great extent though many such methods have been invented. In only a few special cases have they been used in the United States; but in England and also on the Continent of Europe a number of surface-contact roads have been in operation long enough to demonstrate their reliability and safety. These roads are more expensive to install than those using an overhead trolley, but they are less expensive than open-conduit roads, are cheaper to maintain, and are equally effective so far as avoiding overhead wires is concerned. It is reasonable, therefore, to expect that surface-contact systems will find wider application in the future than they have in the past. All electromagnetic systems are more or less complicated, and of all the switching devices that have been invented comparatively few have been commercially operated.

**11.** The general arrangement of such systems is shown in Fig. 5, where $G$ is the generator with its negative terminal connected to the track rails, as in the overhead-trolley or third-rail systems. Insulated contact plates $r, r$ are

mounted between the rails and project slightly above the pavement. In most systems, these contacts are in the form of small plates of hard steel designed to withstand the wear caused by traffic and by the current-collecting shoe on the car. Each contact is connected to the positive working conductor *m* through a switch *s* that is so arranged that the contact plate is connected to the live conductor only while the

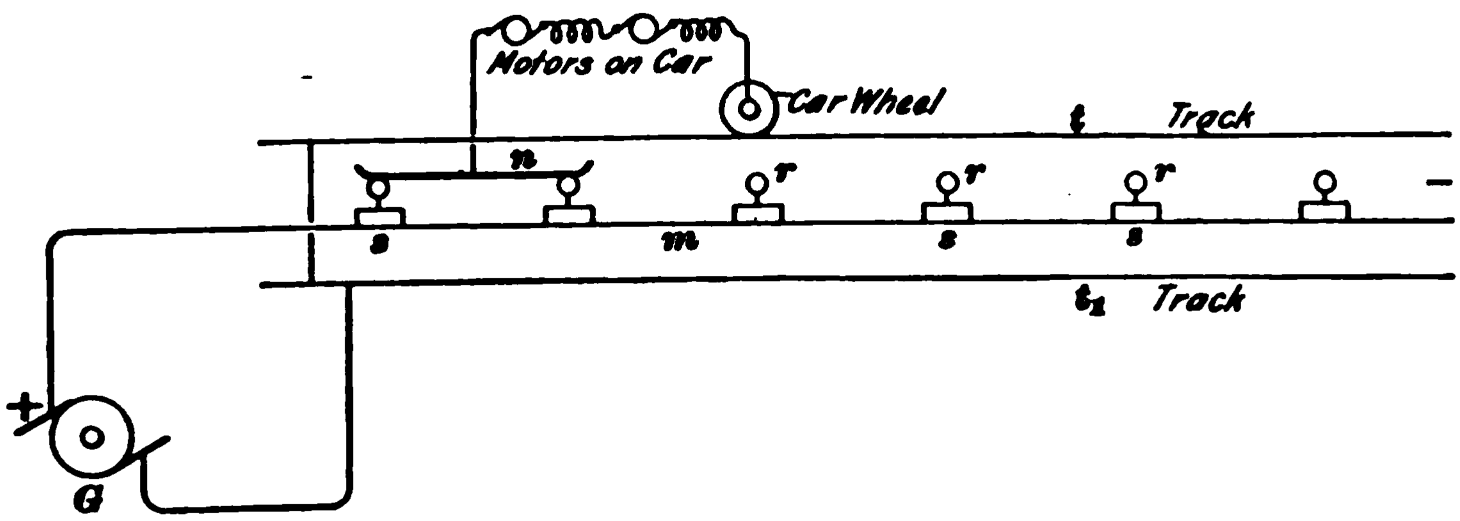


FIG. 5

car is over the plate. Thus, as the car moves along the switches operate, and the car is supplied with current by means of a shoe *n* that slides over the contact plates. In some systems, the switches are grouped in manholes, and operated electrically by means of solenoids or electromagnets; in others, the switches are placed under the contact plates and operated by means of powerful magnets carried underneath the car.

**12. General Electric System.**—Fig. 6 shows the essential features of the **General Electric surface-contact system,** which belongs to the class in which the switches are operated by means of solenoids. Two rows of contact studs *N*, *N* are placed between the rails; the negative terminal of the generator connects to the track rails and the positive conductor connects to one of the fixed contacts of each of the switches *K*, as shown. The operating coils of the switches are connected between the lower rail and the lower row of contact studs; the studs in the upper row are connected to the remaining fixed contacts on the switches as shown. Each car is equipped with a small storage battery *B*, which is kept charged by passing a portion of the motor current through it; this battery is used to operate the

surface-contact switches when the car is started and also for lighting the car. The car is equipped with two long shoes, and when it is in motion the current takes the path indicated by the arrows, flowing from the positive working conductor through the switch contacts to the upper contact stud, thence through the motor, or combination of motors, through the lower shoe and contact stud, and back to the rail by way of the magnet coil. The current passing through the coil holds up the switch, and as the car moves along, successive switches are

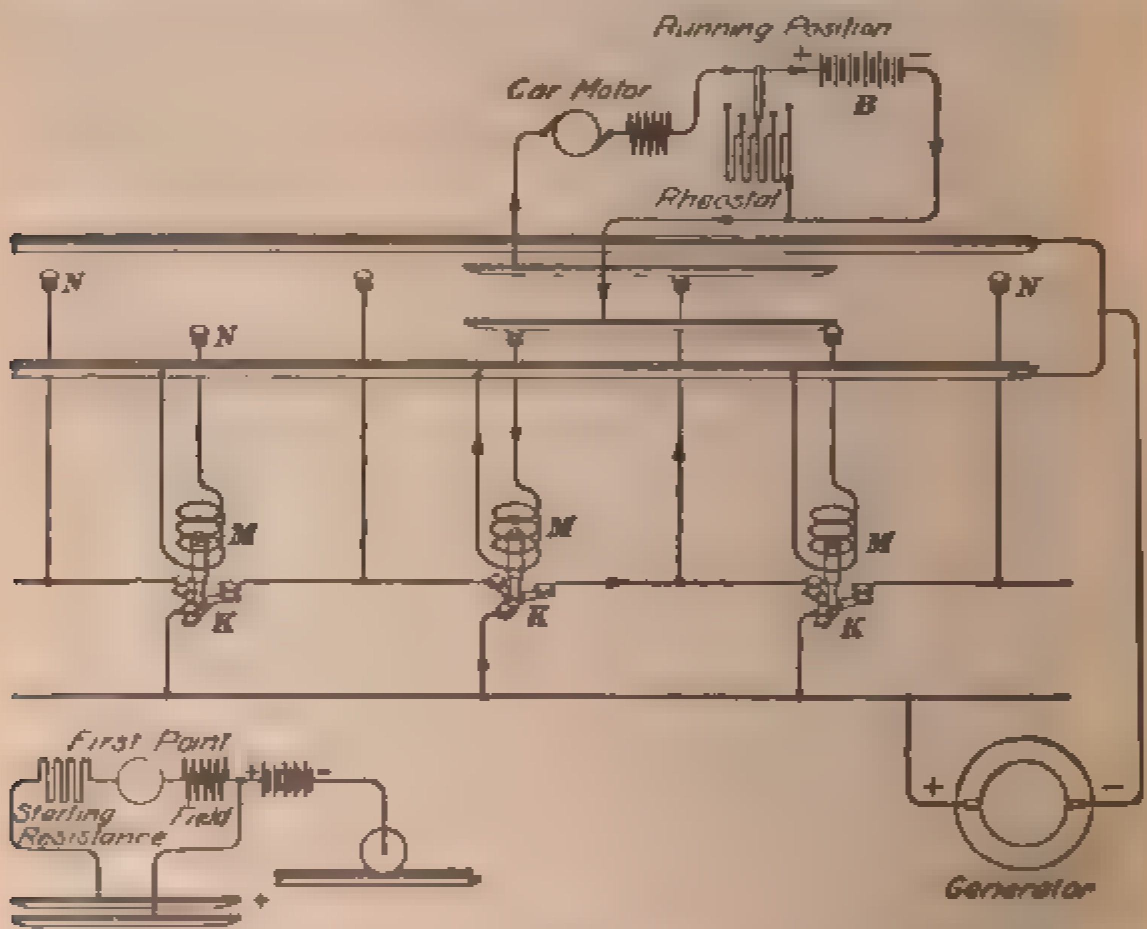


FIG 6

brought into action, thus maintaining the path for the current through the car. The only live studs are those under the car, and as soon as the car moves off the studs become dead; there is thus no danger of shock unless some of the switches fail to operate. When the car is started, current must be supplied from the storage battery in order to operate the switch; this is done by making the connections at starting as shown in the small diagram, where the battery is connected between the lower shoe and rail, thus raising the switch and

allowing current to pass through the motors. As soon as the car has started, the main current operates the switches and the battery is no longer required for this purpose. By making the shoes long enough so that the forward stud is touched before connection with the one in the rear is broken, the forward switch will pick up before the rear one drops, thus maintaining the circuit and avoiding arcing at the switch contacts. In an actual installation, the switches are not distributed along the track, but those corresponding to about 200 yards of track are placed in a vault or manhole and connected to the studs by means of underground cables.

**13. Lorain System.**—As an example of a surface-contact system where the switches are operated by means of magnets carried under the car, the **Lorain system** may be taken. This method is in successful operation for regular city traffic, and continuous use has shown that the danger from shock on account of switches failing to work is negligible. A switch is placed directly beneath each contact plate. The upper switch contact connects to the plate and the lower contact to the working conductor through a flexible copper ribbon. The lower contact is mounted on a thin iron plate, and a series of magnets suspended under the car, with their poles near the surface of the ground, attract the plate with the lower contact and draw it up, thus bringing the lower contact against the upper one and establishing connection between the contact plate and the feeder. The contact plates and switches are placed 10 feet apart and the magnets under the car extend over a length of 16 feet. Thus, two switches are always closed at the same time; the forward switch is picked up before the rear one is dropped and there is no breaking of the circuit when a switch opens. The collecting shoe extends over two contacts, as in Fig. 5, and there is thus a continuous collection of current. As soon as the magnets pass from a switch, the iron plate, carrying the lower contact, drops, thus leaving the plate dead after the car has passed. The switch contacts are made of carbon so that there is very little danger of sticking.

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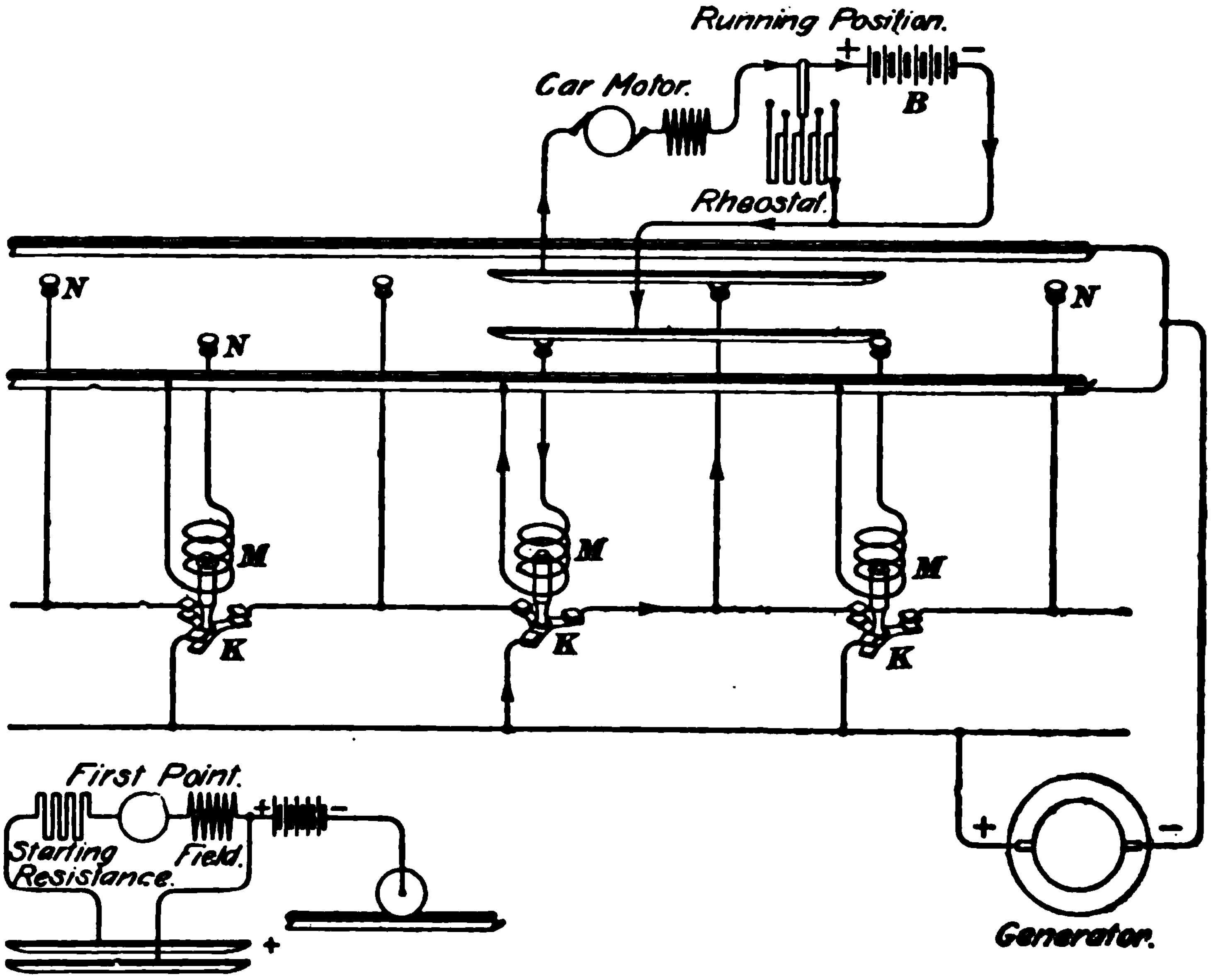


FIG. 6

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600-volt bus, thus allowing a drop of 100 volts in the long feeders. By using this method, the district supplied may extend for a radius of 10 or 12 miles from the power house.

**18.** Fig. 7 illustrates a plan of connections where high- and low-potential bus-bars are provided. Generators *1*, *2*, *3* are compound wound, as is always the case in street-railway

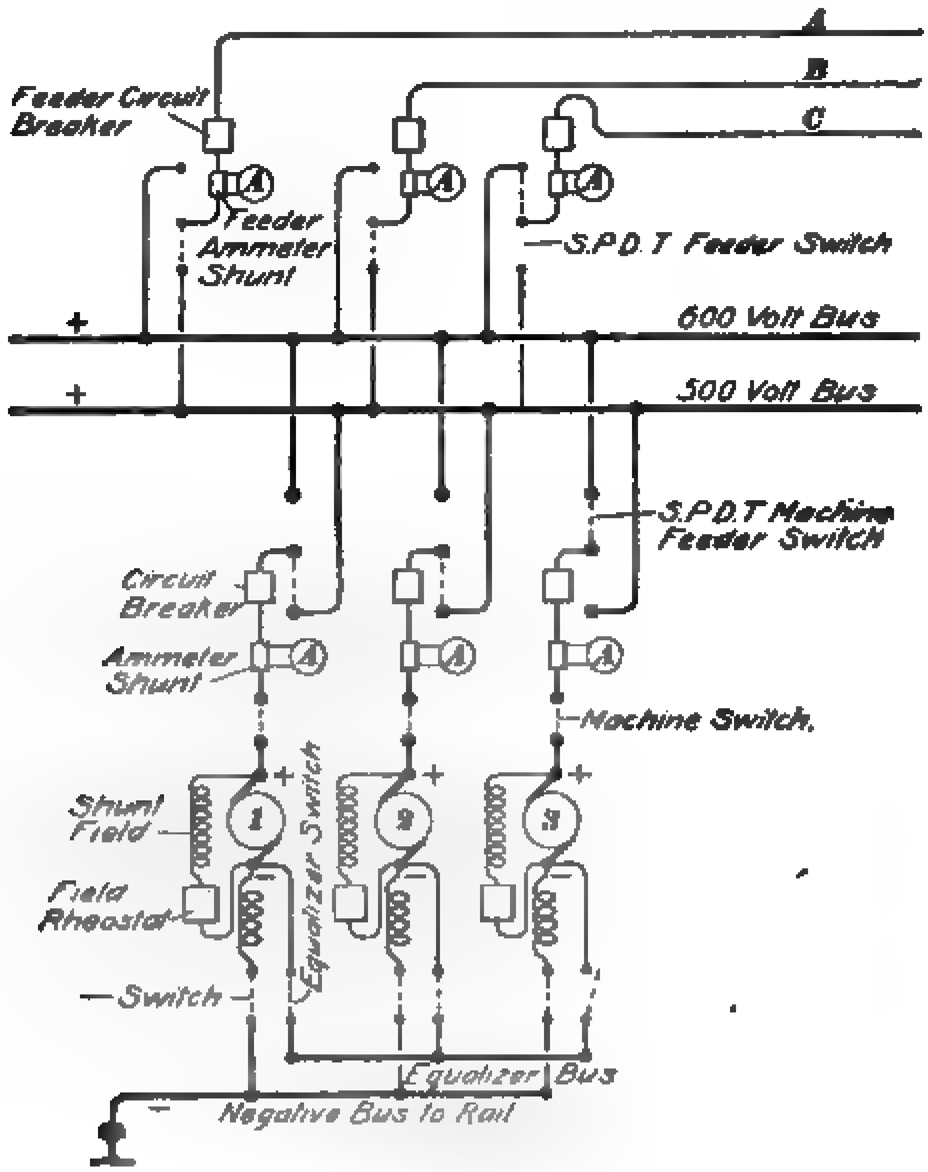


FIG. 7

power stations, and their − terminals are connected to the rail bus-bar. Each + terminal is connected through a main switch, ammeter, and circuit-breaker to the middle point of a single-pole double-throw switch, by means of which the + side of the generator can be connected to either the upper or lower bus-bar.

In Fig. 7, machines *1* and *2* are connected to the lower bar and are operating in parallel, their equalizing switches being closed. Machine *3* is connected to the upper bus, as indicated by the dotted position of the machine feeder switch. Most standard railway generators will generate 600 volts without difficulty, and machine *3* is supposed to generate 600 volts while *1* and *2* generate 500 volts. With the connections shown, any machine can be connected to either bus-bar. The feeders are also provided with single-pole double-throw switches to enable any feeder to be connected to either bus. Thus, if feeders *A* and *B* were supplying near-by sections, or if the load on them were light, they could be run from the 500-volt bus; while if feeder *C* supplied a distant or heavily loaded section it could be connected to the 600-volt bus by throwing its switch to the upper position, as indicated. By this method, a fairly uniform voltage can be maintained at the cars under widely varying conditions of load and distance of transmission. It should be noted, Fig. 7, that the generators are equalized on the — side, a practice that is now very common in railway plants. The — main switch and the equalizer switch are mounted side by side near the machine, and the negative leads are carried directly to the rail bus, thus simplifying the conditions.

## BOOSTERS

**19.** When a road operates several sections a long distance from the power house, the generators, even when run at 600 volts, may not furnish sufficient pressure to make up for the large drop in the feeders. In such cases the road may be operated, without using high-pressure alternating-current transmission, by using *boosters* in connection with the main generators. A booster is a generator connected in series with the feeder or feeders on which the voltage is to be raised, in such manner that the voltage that it generates is added to that of the main generators, thus increasing the voltage applied to the feeders by the amount of the pressure generated by the booster.

In Fig. 8, *a* represents the armature of the main generator and *b* the booster armature. Short feeders supplying near-by sections are connected to the + bus-bar of the generator in the usual manner. Long feeders are connected to the + bus-bar through the booster, which in this case is supposed to generate 200 volts. For railway work, boosters are nearly always of the series type; i. e., the field winding is in series with the armature so that the voltage generated increases in proportion to the current that passes through the booster. Thus, when the load on the long-distance feeders

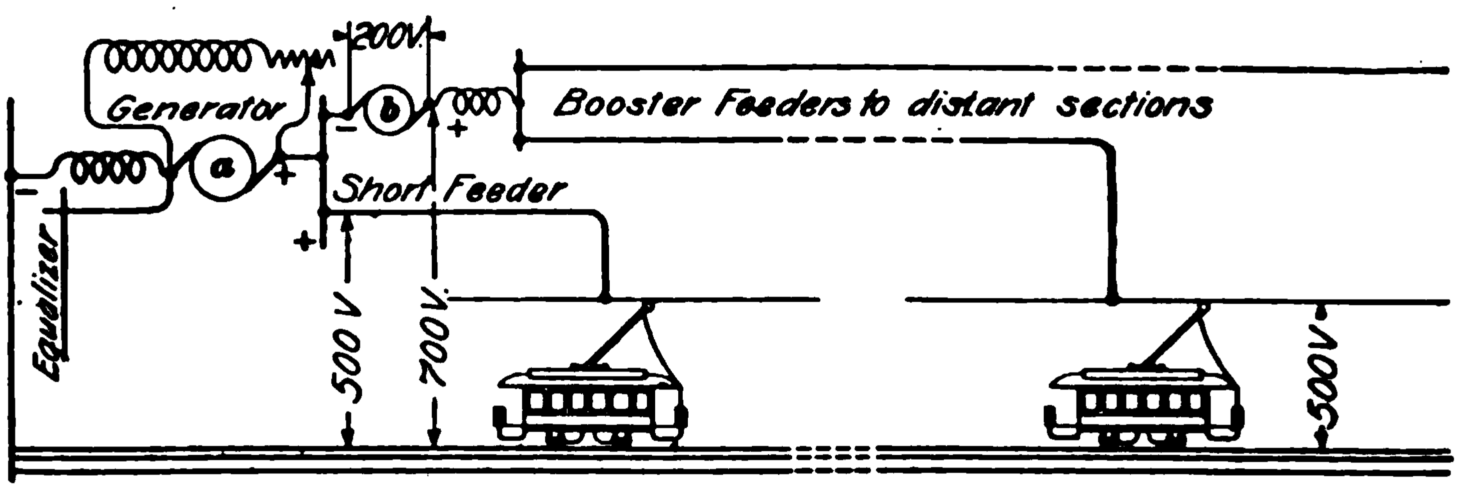


Fig. 8

is light, the booster voltage is low because the field is weak. When a heavy load comes on, the booster voltage increases and automatically compensates for the drop in the long feeders supplied through the booster. If the booster were shunt or compound wound and thus generated a practically constant voltage regardless of the current supplied over the feeders, an excessive voltage would be applied to the cars at light loads because there would then be little loss in the line to take up the booster voltage.

**20. Method of Driving Boosters.**—Boosters are nearly always driven by means of shunt-wound motors. Fig. 9 shows a typical General Electric booster set, consisting of a shunt-wound motor *M* coupled to a series-wound booster *B*. Boosters do not differ in their general construction from other dynamos, except that their commutators are often larger than on standard generators, because of the large current that they carry in proportion to their size. Boosters could be driven by steam engines or any other convenient

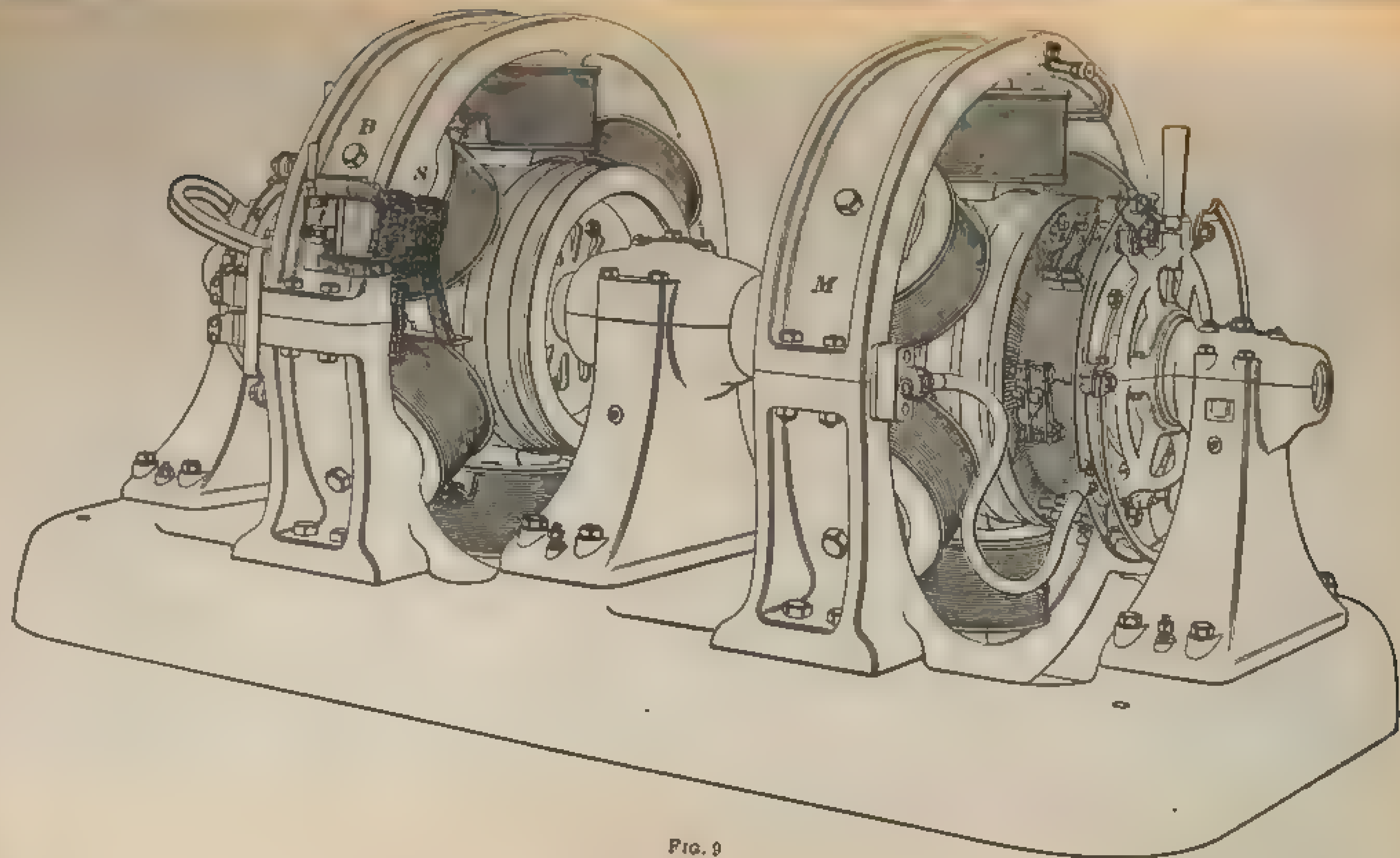


FIG. 9

source of power, but in most railway power plants electric motors supplied from the main generators are used.

**21. Output of Boosters.** The output of a booster, in watts, is equal to the product of the number of amperes passed through the booster and the number of volts by which the pressure is raised. Thus, if a booster carries 600 amperes, and if when this current is passed through it 200 volts is generated, the output of the booster is $600 \times 200 = 120{,}000$ watts, or 120 kilowatts. If the current dropped to 300 amperes, the voltage generated would, since the booster is series-wound, drop to about half the full-load voltage, i. e., 100 volts, and the output would then be $300 \times 100 = 30{,}000$ watts, or 30 kilowatts Thus, the loss in the line is compensated for automatically and the voltage at the cars remains nearly constant notwithstanding fluctuations in load.

The booster output for any given case will depend on the current taken by the feeders that require boosting. A common size that has been found well adapted for average railway service has an output of 120 kilowatts, or 600 amperes at 200 volts. For smaller roads, an output of 60 kilowatts or 600 amperes at 100 volts will be found convenient The booster shown in Fig. 9 is provided with a shunt *S* connected across the field winding. When switch *t* is closed, part of the current flows through *S* and the voltage added by the booster is less than when *t* is open Thus, the boosting effect can be changed in case the feeder does not require the addition of the full booster voltage.

**22. Booster Connections.**—A booster must always be connected in series with the feeder or group of feeders in such manner that its voltage will be added to that of the main generators. Thus, the terminal of the booster must connect to the + bus-bar of the generator. Fig. 10 shows a plan of connections for a motor-driven booster. The main generators *1*, *2*, *3* connect to the + bus-bar in the usual manner and the + bus connects to the − booster bus through switch *a*. Each feeder is provided with a double-throw single-pole switch *b*, by means of which it can be connected

either to the main + bus or to the + bus of the booster. As indicated by the dotted lines, the long feeders $A, B$ are connected to the booster, while short feeder $C$ is supplied with current directly from the main generator. The booster is driven by a shunt motor supplied with current from the main generators, and equipped with a circuit-breaker and

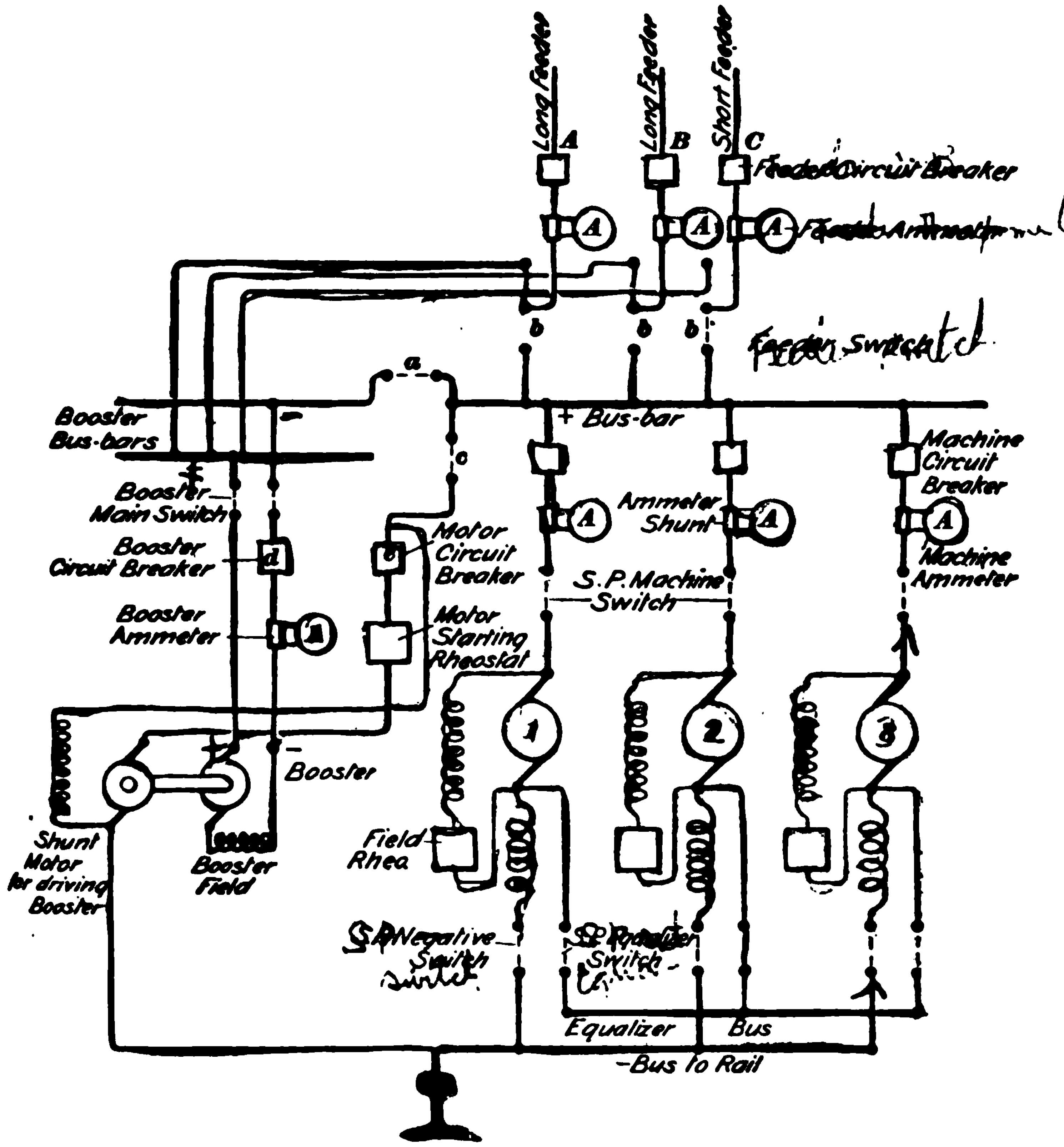


FIG. 10

starting rheostat. The booster is connected to the booster bus-bars through an ammeter, circuit-breaker, and double-pole main switch. By following out the connections in Fig. 10, they will be found equivalent to the elementary connections in Fig. 8; all current supplied to feeders $A$ and $B$

passes through the booster and the voltage applied to them is increased by an amount proportional to the current.

The motor circuit-breaker should be arranged so that in case it opens the motor circuit, the current will also be cut off from the booster. The simplest way of doing this is to mount the two circuit-breakers *d*, *e* side by side and have them interlocked so that when *e* flies out, *d* will also open. They should also be arranged so that *d* cannot be closed until after the motor has been started. If current were cut off from the motor but not from the booster, the latter would be driven as a series motor and an unloaded series motor on a constant-potential circuit will race badly. If, therefore, the current is not shut off promptly damage may result.

**23. Booster Used With High- and Low-Potential Bus-Bars.**—By combining a booster with the connections shown in Fig. 7, a number of voltages may be made available. Thus, in Fig. 11, the long feeders *A*, *B* are con-

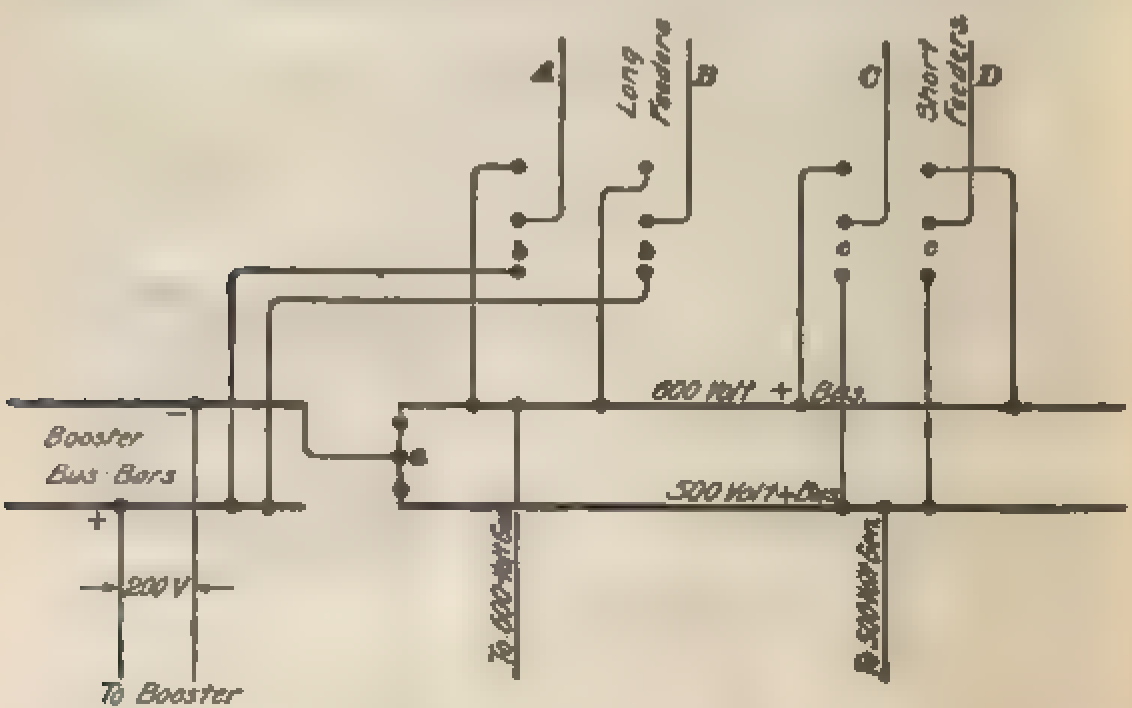


FIG. 11

nected to double-throw switches *b*, *b*, by means of which they can be connected either to the booster or to the 600-volt bus. The shorter feeders *C*, *D* can be connected through double-throw switches *c*, *c* to either the 500-volt bus or 600-volt bus. A double-throw switch *a* permits the

booster to be connected to either machine bus. Thus, assuming that the maximum booster voltage is 200, the maximum voltage applied to feeders *A*, *B* may be either 600 or 800. Short feeders can be supplied with either 500 or 600 volts, thus giving a flexible arrangement that allows the voltage to be suited to the demands of any particular section of the road.

**24. Convertible Booster.**—It is possible to arrange one of the regular station generators so that it can be used as a booster if necessary; this is often convenient on small roads or for temporary work where it would not pay to

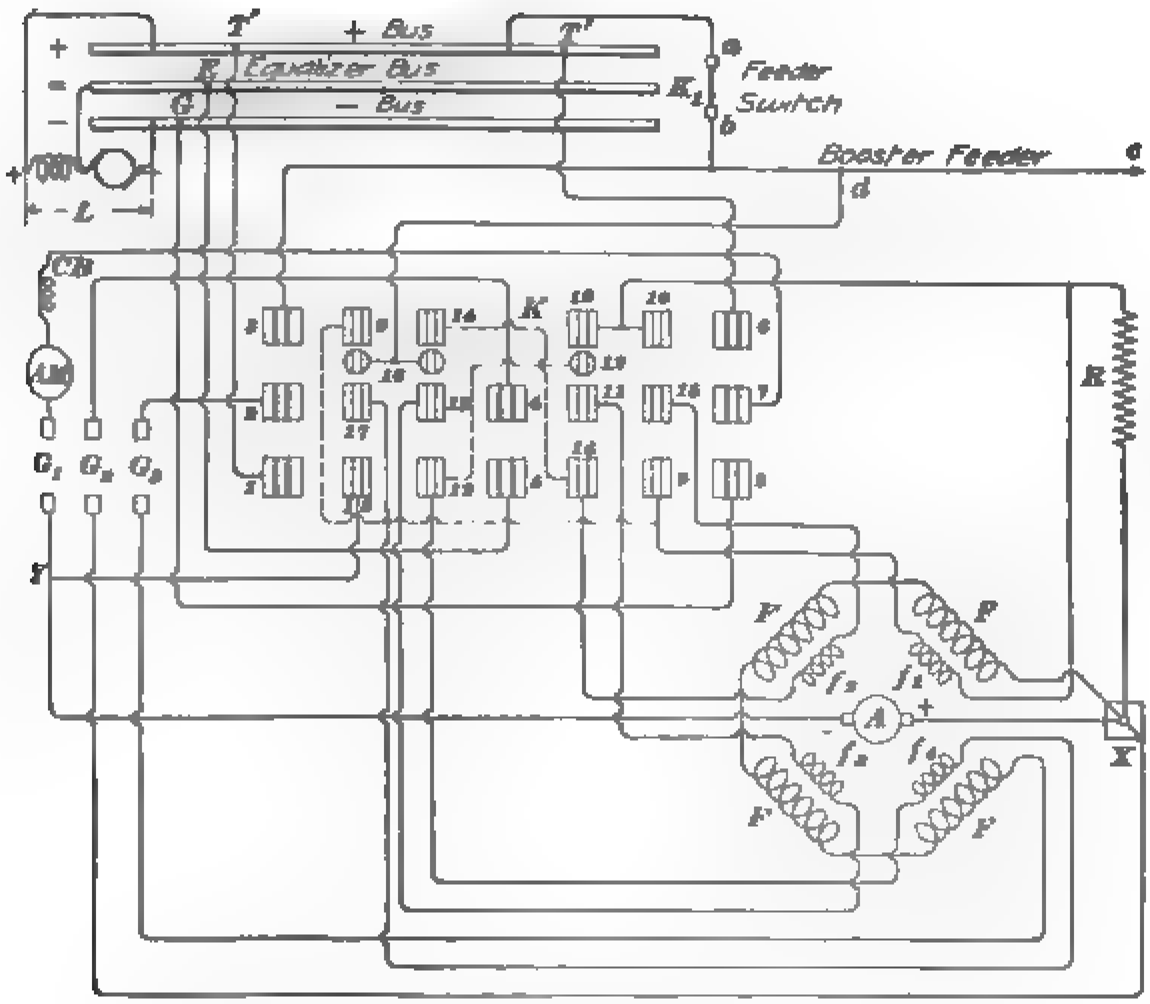


FIG. 12

install a regular booster. A machine so used should be arranged so that it can normally be run as a regular generator and by means of suitable switches changed over to act as a booster, as shown in Fig. 12, where *L* is one of the regular generators connected to the bus-bars.

In this case the +, −, and equalizer bars are shown together, but the negative and equalizer bars may be located near the generators; also, the machines are shown equalized on the + side; but this is immaterial so far as the general plan of connections is concerned. The convertible booster is shown in the lower right-hand corner, $F, F, F, F$ being the series field coils and $f_1$, $f_2$, $f_3$, $f_4$ the shunt coils. With a machine of this kind, the series coils alone will not give sufficient excitation, so that it is necessary to use the shunt coils also. $G_1$, $G_2$, $G_3$ are the main generator switches and $K$ is a special double-throw switch for changing over the connections so that the machine acts either as a booster in series with the booster feeder or as a regular generator in parallel with $L$ or other generators that may be in service. When $K$ is thrown to the upper position, the machine acts as a booster; but before it can do so, feeder switch $K_1$ must be opened. When $K$ is thrown up, block *2* is connected to *3*; *7* to *6*; blocks *9*, *14*, *16*, *17*, and *13* are connected together, as are also blocks *10*, *11*, *12*, and *15*. The series coils of the machine are connected in series, but the shunt coils are connected to separate terminals so that they can be connected in series when the machine is used as a generator and in parallel when used as a booster. $T'$ and $b$ are the terminals of the booster and when $K_1$ is closed, the feeder connects directly to the bus-bar, the booster terminals being short-circuited. When $K_1$ is open, all current supplied to the feeder must pass through the booster. Neglecting the shunt field for the present and assuming that $K_1$ is open and $K$ thrown to the upper position, the path of the current from generator $L$ is as follows: $L+$–$T$–$T'$–*6*–*7*–$CB$ (circuit-breaker)–$AM$ (ammeter)–$G_1$–$A-$–$A+$–$X$–$F$–$F$–$F$–$F$–$G_2$–*2*–*3*–$c$ and back to $L-$ by way of the cars and track. When $K_1$ is closed, the path is $L+$–$T$–$a$–$K_1$–$b$–$c$, and the booster is cut out. The shunt field is excited by connecting the four coils in parallel so that a low voltage will provide sufficient excitation. The voltage for exciting the shunt coils is obtained by connecting them in parallel with a certain length of the feeder, thereby subjecting them to a

pressure equal to the drop in that part. Thus, the shunt coils are subjected to a voltage that varies with the current supplied over the feeder and their excitation will be proportional to the current; their effect will, therefore, be the same as if an equal number of ampere-turns were supplied by coils connected in series. One end of coil $f_1$ connects to block *9* and the other end to *10*; the ends of $f_2$ connect to blocks *14* and *15*; $f_3$ to *11* and *13*; and $f_4$ to *12* and *17*. When the booster switch is thrown up, similar ends of the shunt coils are connected together, positive ends being connected to blocks *10*, *11*, *12*, and *15* and negative ends to *9*, *13*, *14*, and *17*. Block *16* connects to the feeder at some point $d$ determined by the amount of feeder required to give the drop necessary for the excitation of the shunt field. When switch $K$ is thrown down, the path of the current is $A+ -X-F-F-F-F-G_2-2-1-T$; out on the line by way of switch $K_1$ and feeder $c$ to the cars and thence back to the rail bus-bar $G$ through $8-7-CB-AM-G_1-A-$. The shunt coils are now in series, as shown by the path $A+ -X-R-f_1$ $-9-15-f_2-14-11-f_3-13-12-f_4-17-18-Y$ and current flows through them in the same direction as through the series coils.

**25. Location of Booster.**—Boosters are nearly always located in the power house. If located at any point out on the line they will, as a rule, entail an additional charge for attendance; and if motor-driven the power for their operation will have to be transmitted from the station, thus increasing the line loss. If the boosters were driven from some other source of power, this latter objection would not count, but there would still be the cost of attendance, which amounts to practically nothing when the boosters are placed in the power station, as they require such a small amount of attention that no additional help is required.

**26. Economy of Booster.**—At first glance, the use of boosters for supplying distant parts of a railway system appears to be a very uneconomical method and that it would be much better to use high-tension alternating-current transmission with substations situated near the outlying districts.

It takes power to drive a booster, but it is only expended while it is needed, and the load on a given booster may be quite light for the greater part of the time. That is, a booster wastes a considerable amount of power only when the load is heavy. Again, with alternating-current transmission there is considerable loss in the transforming devices that is the same no matter what the useful load on a substation may be, and the annual cost of attendance alone for a substation may more than counterbalance the cost of power wasted by a booster, as compared with the cost of power wasted with alternating-current transmission. The use of boosters allows a given system to be extended without making any change in the generating equipment already installed, and distant sections can be fed without an excessive outlay for copper. These advantages are still more fully realized if storage batteries are installed out on the line and charged from the booster feeders. The batteries will charge during periods of light load and discharge when the load is heavy, thus keeping a fairly uniform load on the feeder and working it to best advantage.

It is thus seen that the annual cost of operation with boosters may be actually less than with alternating-current transmission, and the question as to which is the best method for a given road is one that can only be decided by a very careful comparison of the cost of operation under the two systems. Roads are in regular operation where cars are run over a radius that in some cases exceeds 20 miles, by the use of boosters and storage batteries. These roads give satisfactory service, they are fully as economical in their operation as similar roads for which alternating-current transmission is used, and are less liable to interruptions from breakdowns in the various transforming appliances necessary with alternating-current transmission and direct-current distribution from substations.

## ALTERNATING-CURRENT SUPPLY

### POLYPHASE TRANSMISSION

**27.** Where roads are such that it is necessary to transmit the power for their operation by means of high-tension alternating current, the general practice has been to use two-phase or three-phase transmission and change to direct current by means of rotary converters located in substations. In some cases, as, for example, at Niagara Falls, current is generated by two-phase machines and transmitted as three-phase by connecting the step-up transformers on the Scott plan. On some of the largest systems, the alternators are wound for pressures as high as 11,000 volts and feed directly into the distributing system without the use of step-up transformers. Revolving field alternators are now almost universally installed in preference to those of the revolving armature type.

**28.** Fig. 13 shows the general scheme of distributing current for the Manhattan Elevated Railway, of New York. Current is generated in one large central station by revolving-field three-phase alternators direct-connected to 8,000-horsepower engines. The use of the revolving-field type of machine enables the current to be generated at 11,000 volts in the machine. It is distributed by means of heavily insulated lead-covered cables, run in underground conduits, to a number of substations, and there passed through stationary transformers that step-down the voltage. The rotary converters change the alternating current to direct current at about 625 volts, and from the substations it is supplied to the cars by means of a third rail and the ordinary track. The systems of distribution used by the Metropolitan Railway Company, of New York, and the London Underground are almost exactly the same as this one, except that the distributing pressures are somewhat lower. In the case of the Metropolitan road the distributing pressure is 6,600 volts.

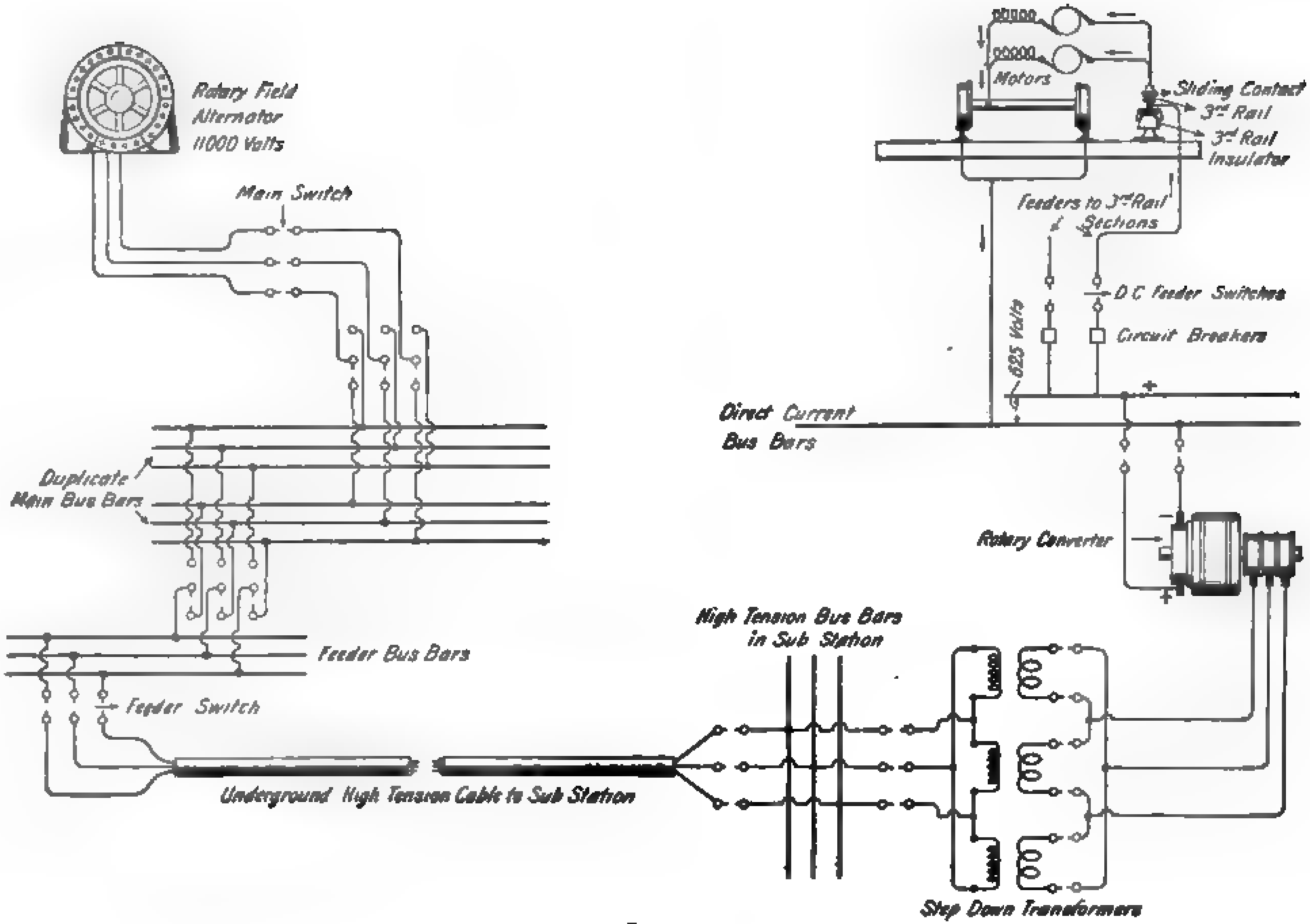
Rotary Field
Alternator
11000 Volts
Main Switch
Duplicate
Main Bus Bars
Feeder Bus Bars
Feeder Switch
Underground High Tension Cable to Sub Station
High Tension Bus Bars
in Sub Station
Step Down Transformers
Rotary Converter
Direct Current
Bus Bars
625 Volts
Circuit Breakers
D.C. Feeder Switches
Feeders to 3rd Rail
& Sections
Motors
Sliding Contact
3rd Rail
3rd Rail
Insulator

FIG. 18

On some roads, where a considerable part of the power is required near the station in the form of direct current, it may be advisable to use double-current generators and step-up the alternating current for transmission to the distant parts of the system. In most cases, however, where both alternating and direct currents are required it is better to install alternators, which are simpler than double-current machines, and obtain what direct current is required by means of rotary converters.

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### SINGLE-PHASE TRANSMISSION

**29.** The use of **single-phase motors** on electric cars is such a recent development that practice has not become settled regarding the best methods of distribution to be used. A number of plans are available and the one adopted in any given case will depend largely on whether the road is to be supplied from an existing transmission system or

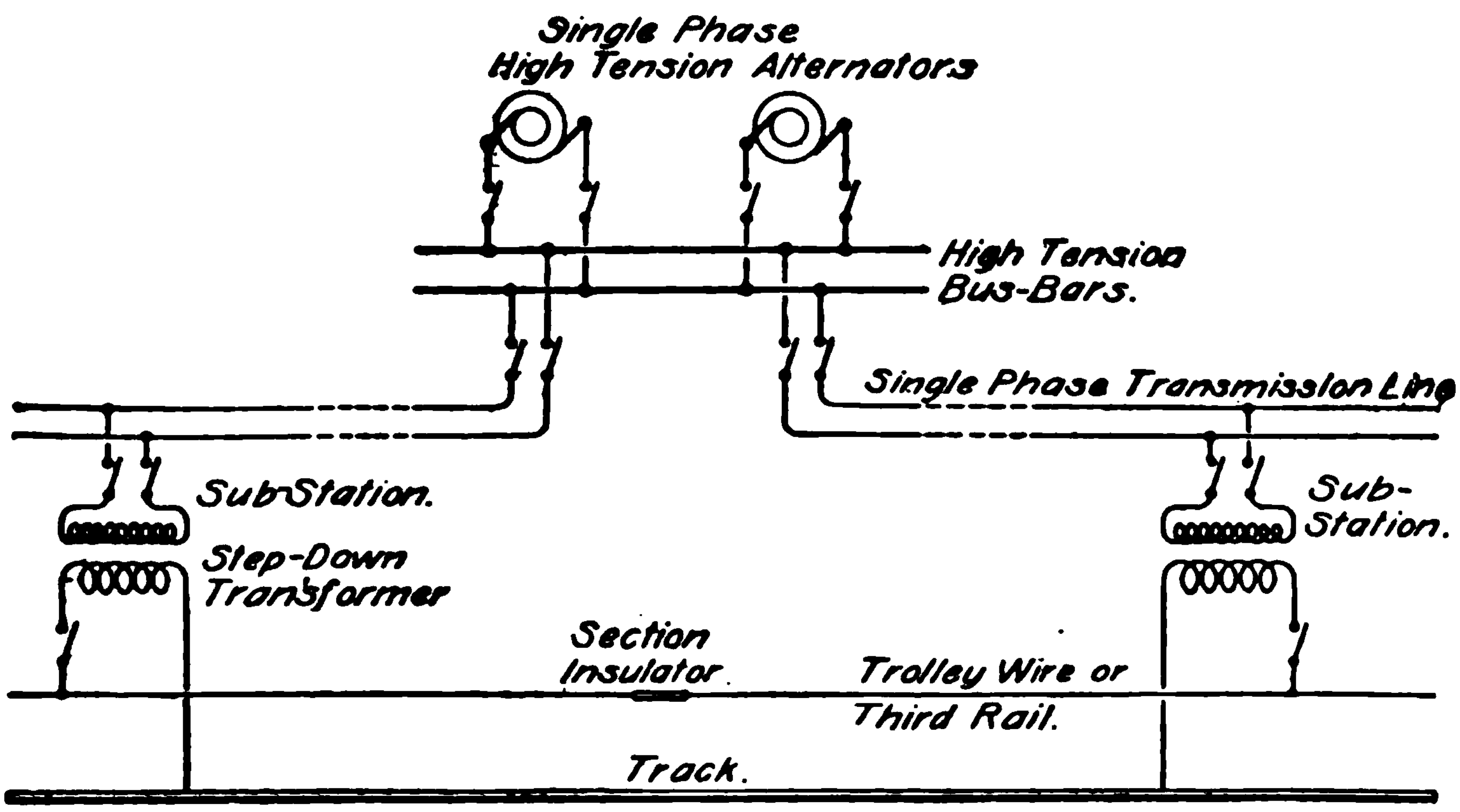



FIG. 14

whether new apparatus is to be installed throughout. Fig. 14 shows a plan where single-phase generators are used, the line voltage being stepped-down by transformers. This is the simplest plan and the one that would quite likely be adopted in case a new outfit were to be installed throughout. The trolley might be worked at a pressure of 2,000 to 3,000 volts

and the transmission carried out with a line pressure of 20,000 or 30,000 volts. It should be noted in Fig. 14 that adjacent sections of the trolley wire are at the same potential and that, under ordinary working conditions, there is no electric strain on the insulator used to divide the trolley wire into sections.

There are so many large transmission plants already in operation on the two-phase and three-phase systems that cases will frequently arise when single-phase railroads must be operated from them. This can be done by splitting the road into a number of sections and distributing them on the different phases so as to keep the load approximately balanced, thus

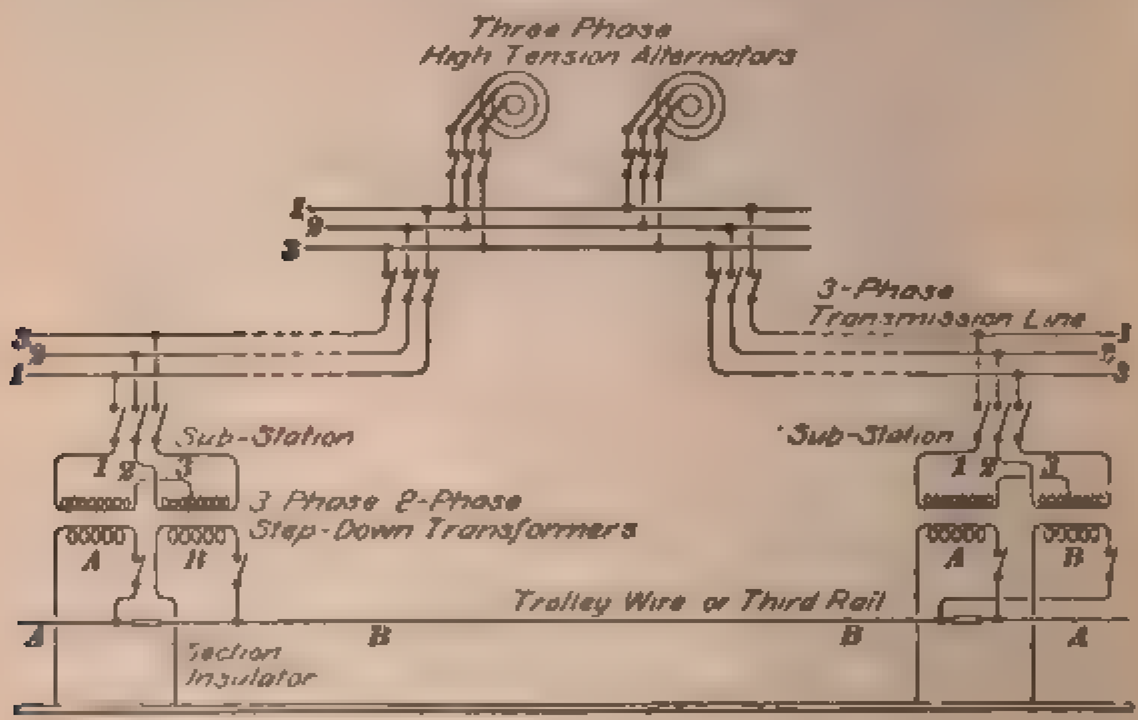



FIG. 15

making the system more complicated than if single-phase distribution were used throughout. Fig. 15 shows a scheme whereby a single-phase road is supplied from three phase alternators. In the substations, the current is transformed from three-phase to two-phase by the Scott arrangement of transformers and alternate trolley sections are fed from different phases, thus balancing the load. By transforming from three-phase to two-phase, the secondary connections are considerably simplified. With this plan the trolley-section insulators are always subjected to a high pressure.

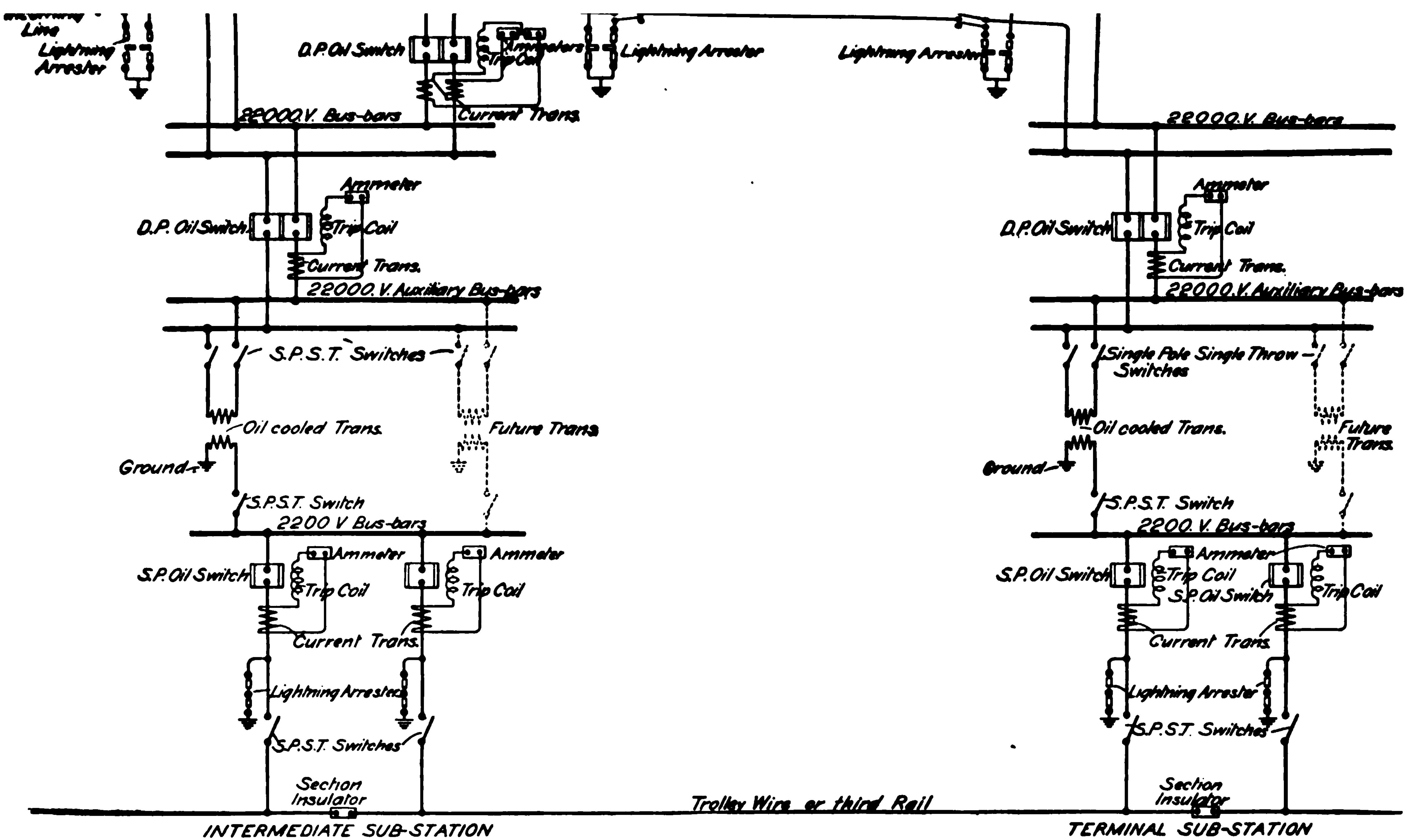
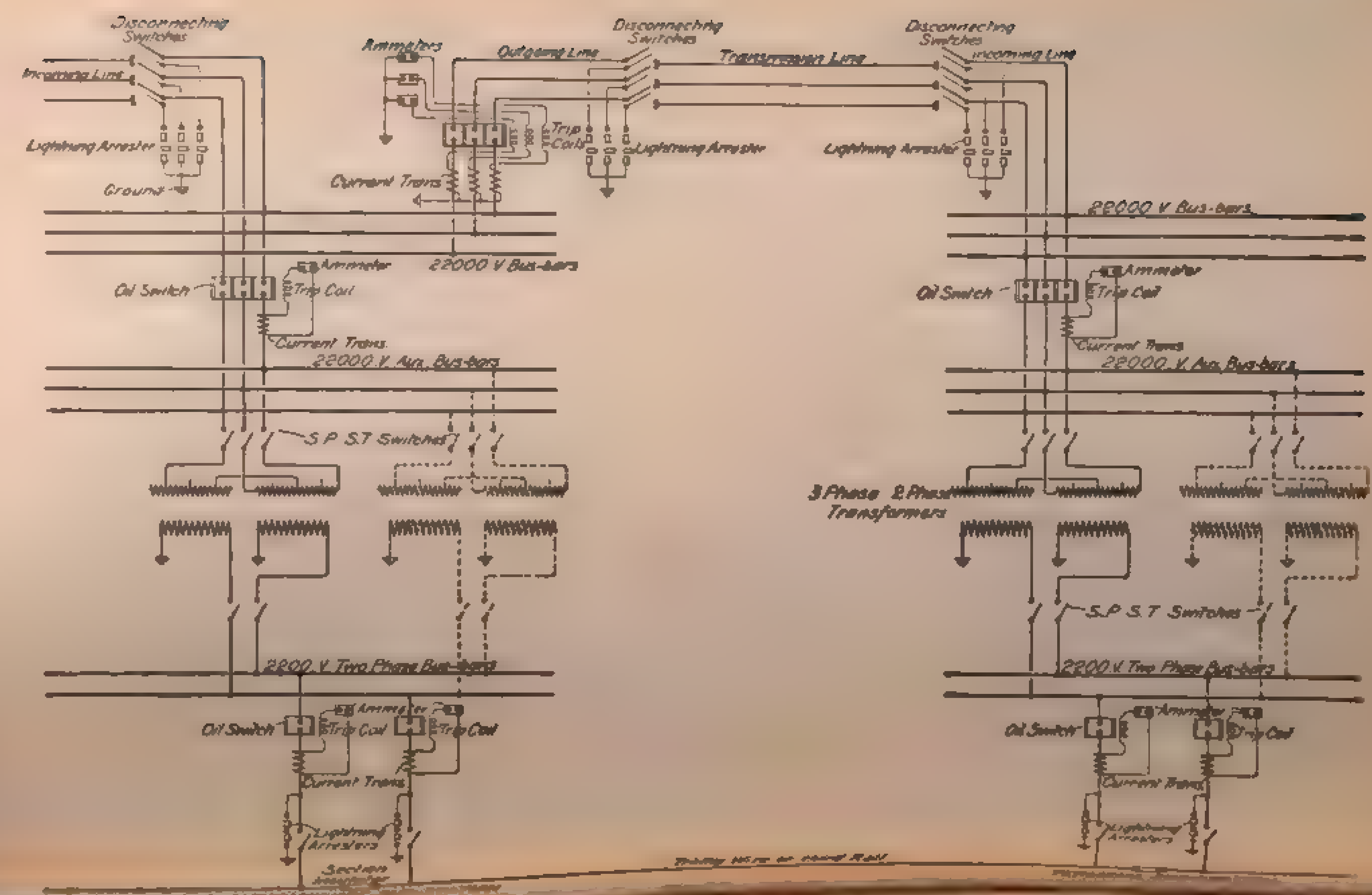

Line
Lightning Arrester
D.P. Oil Switch
Ammeters
Trip Coil
Lightning Arrester
Lightning Arrester
22000 V. Bus-bars
Current Trans.
22000 V. Bus-bars
Ammeter
D.P. Oil Switch
Trip Coil
Current Trans.
22000 V. Auxiliary Bus-bars
Ammeter
D.P. Oil Switch
Trip Coil
Current Trans.
22000 V. Auxilliary Bus-bars
S.P.S.T. Switches
Single Pole Single Throw Switches
Oil cooled Trans.
Future Trans.
Oil cooled Trans.
Future Trans.
Ground
Ground
S.P.S.T. Switch
2200 V Bus-bars
S.P.S.T. Switch
2200 V. Bus-bars
Ammeter
Ammeter
S.P. Oil Switch
Trip Coil
Trip Coil
Ammeter
S.P. Oil Switch
Trip Coil
S.P. Oil Switch
Trip Coil
Current Trans.
Current Trans.
Lightning Arrester
Lightning Arrester
S.P.S.T. Switches
S.P.S.T. Switches
Section Insulator
Trolley Wire or third Rail
Section Insulator
INTERMEDIATE SUB-STATION
TERMINAL SUB-STATION

FIG. 16


Disconnecting Switches
Incoming Line
Lightning Arrester
Ground
Ammeters
Outgoing Line
Disconnecting Switches
Transmission Line
Trip Coils
Lightning Arrester
Current Trans.
Disconnecting Switches
Incoming Line
Lightning Arrester
22000 V Bus-bars
Oil Switch
Ammeter
Trip Coil
Current Trans.
22000 V Bus-bars
22000 V Aux. Bus-bars
S P S T Switches
3 Phase 2 Phase Transformers
2200 V Two Phase Bus-bars
Oil Switch
Ammeter
Trip Coil
Current Trans.
Lightning Arresters
Section Insulator
Trolley Wire or Third Rail

**30.** Figs. 16 and 17 show substation connections for single-phase railways as proposed by the General Electric Company, Fig. 16 showing substations supplied from a single-phase transmission line and Fig. 17 from a three-phase line. The plans are the same as indicated in the elementary diagrams, Figs. 14 and 15, the three-phase current being transformed to two-phase in Fig. 17. Two substations feed into the same trolley section, thus dividing the load between the stations. The substation connections are very simple when compared with those for a station using rotary converters. All that is required in addition to the step-down transformers are the switches and protective devices. There is no moving machinery in the substations, constant attendance is unnecessary, and the use of single-phase motors makes the system as a whole nearly as simple as one using direct current. All switches used for interrupting the current are of the oil-break type; knife switches are provided for disconnecting various parts of the system, but these are not intended for opening the circuits when the current is on.

## THE POWER HOUSE

**31.** Having explained the general methods of supplying current to electric cars from the working conductor, and the different systems available for transmitting the current from the central station to the cars, it will be necessary to take up the different parts of the road and describe them in detail. For this purpose the subject may be considered under the following heads: (*a*) The *power house;* (*b*) the *line and track;* (*c*) the *car equipment.*

### LOCATION OF POWER HOUSE

**32.** The general design of power houses and the class of apparatus to be used in them has been fully covered elsewhere, so that only a few considerations affecting their location will be mentioned here. The power house, or power station, should be situated as near the center of the system

as possible, assuming that it is to be a steam-power plant and that its location is not already fixed by conditions having no connection with the traffic on the road. In the case of water-power plants the site is fixed by the location of the water-power, so that the following cannot, in general, be applied to such roads. By the center of the system is meant the center of the load or traffic. Since wires must be used to convey the power from the power house to the point where it is to be used, a part of the power generated will be lost in them. If they are not of sufficient size, they will cause a loss of power that will make itself very strongly felt in its effect on the speed that the cars make and also on the amount of heat that the motors develop. This loss will

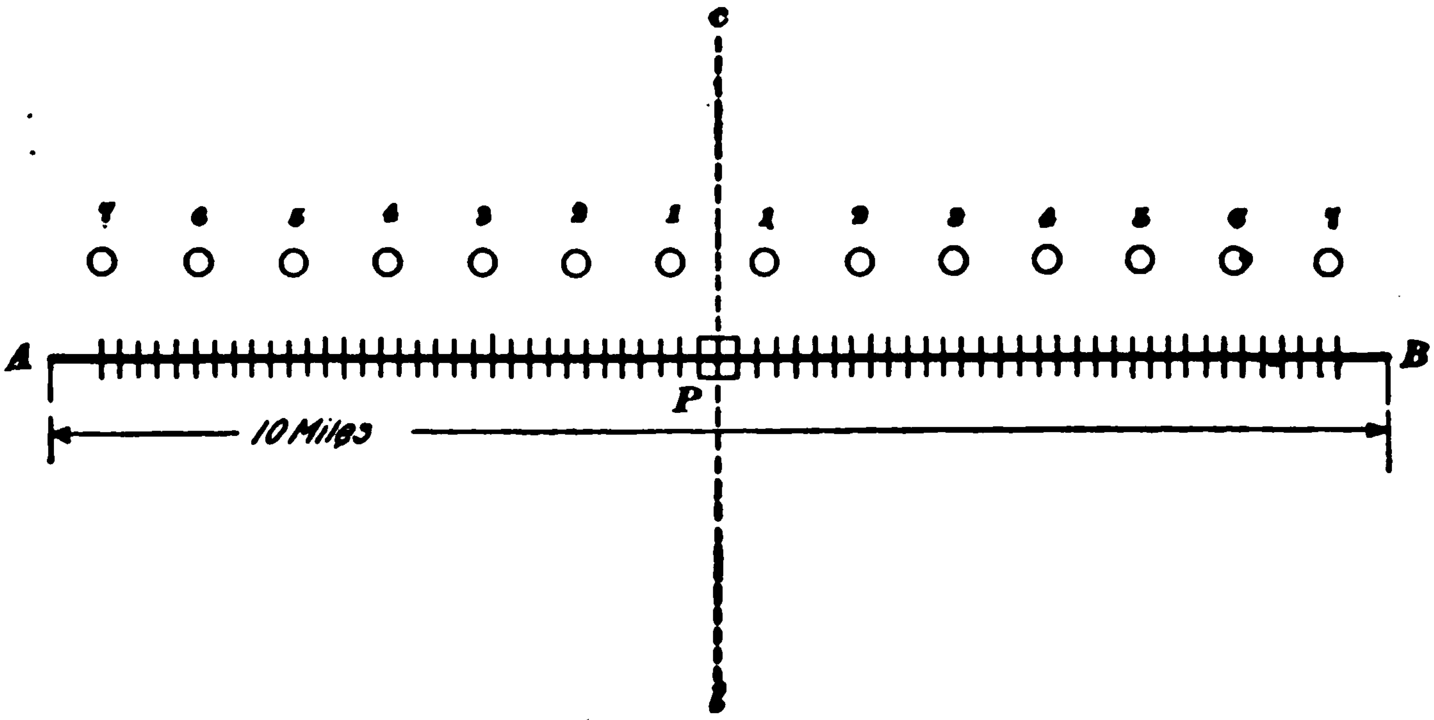



FIG. 18

depend on the resistance of the line and the amount of current that it has to carry. Hence, it follows that the center of the load may not be the geographical center of the system; in fact, these two centers very seldom fall in the same place. The true load center is located in the same way that the center of gravity of any system of bodies is located. The geographical center depends on the number of miles of track and how these are disposed; the load center depends on how the load is distributed.

In Fig. 18, *A B* represents 10 miles of track, free from grades and sharp curves, and on which a certain number of cars, *1*, *2*, *3*, *4*, etc., of about the same weight and equipped

with motors of the same size, run at regular intervals. The geographical center, or center of mileage, is in this case located at *P*, a point midway between the two ends, so that there is 5 miles of track on each side of it. Also, the load center in this case is at *P*; for, suppose that all the cars, except the two on the extreme ends, are running at full speed. Since the track is level and the cars and motors are alike, they will all take about the same power, and since the loads are evenly distributed throughout the length of track, they can be represented by circles of the same size, as shown in Fig. 18. Here there are seven loads on each side of the center line, and if each circle is supposed to represent a weight of a certain number of pounds, the center of gravity of the system will fall on the center line *c l*. So, also, if all cars, except the two end ones, are supposed to stand still or to coast along with the power off, and the two end ones start at the same time, the same load will be drawn to both ends of the line, and point *P* will still be the center of load and will therefore mark the spot where the power house should stand.

It is not implied that the load, even on such a simple layout, will always be as evenly distributed as in this ideal case, for such a condition will be the exception rather than the rule. Suppose *A* to be in the outskirts of a large city and *B* a down-town district; then, in the morning and evening, when people are going to and returning from work, the load leans a little toward the *B* end of the line, but during the rest of the day it is uniformly distributed. To alter conditions, suppose that from the middle of the line to *B* there is an up grade. Those cars that are ascending the grade will be called on to do more work than those on the level or on down grade, so that the ideal site for the station will be shifted toward *B*. In this case, the mileage center remains the same, but the load center is changed.

**33. Influence of Future Extensions.**—In locating the site for the power house, future extension and increase in traffic incidental to the development of outlying districts should be borne in mind and the site selected accordingly.

Suppose, in Fig. 19, that the full-line section $AB$ represents the track put down at the first building of the road and that, in accordance with the demand then existing, the power house was put at $P$, the center of load for $AB$, which is supposed to be level. Now, suppose that the road has been extended to a point $C$, so that $AB = AC$. If it is further assumed that the district through which $AC$ runs becomes built up, it will be only a matter of time when the travel density will be as great on the new stretch of track as on the old, in which case, assuming the different load units to be fairly evenly distributed throughout the distance $BC$, the proper place for the power house would be at point $P'$, midway between $B$ and $C$. So long as $AB$ constituted the

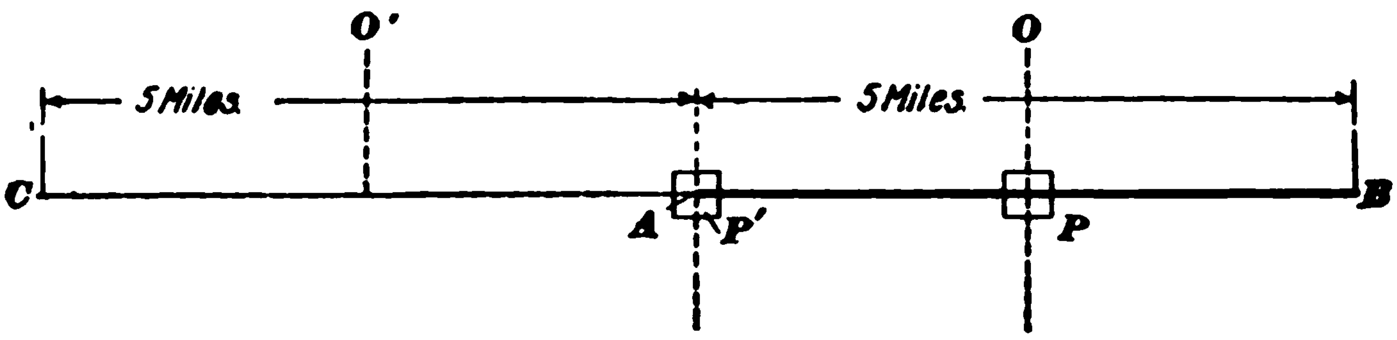



FIG. 19

whole road, the power house situated at $P$ was at the center of an evenly distributed load, and the same loss of power would attend the transmission of a given amount of power to one end of the line as to the other. As soon, however, as the extension $AC$ was started, a power house at $P$ was $2\frac{1}{2}$ miles from the $B$ end of the road and $CA + AP$ or $7\frac{1}{2}$ miles from the $C$ end. Under such a condition, should all the cars, through trouble of some sort, become congested at the far end of the line, the loss incidental to the great distance and to the large current caused by trying to start all the cars at once would seriously delay getting the cars on their time again.

If the station were put at $A$ in the first place, it would, of course, be at one end of the line as long as $AB$ was the whole road, and would not therefore be at the center of load; but if the extension $AC$ were only a matter of time, it would be far better to put up with the line loss due to want of balance on the shorter line, locate the station at $A$, and

be prepared to get the best results when the extension was in operation.

**34.** If, in deciding the best location for the power house, it were only a matter of fixing the probable center of load, the problem would be comparatively easy. But in many cases it is made very hard and almost impossible to solve, except approximately, by the fact that several other considerations enter into the question. The prospective center of the load might be located, from a purely electrical point of view, in a place so situated that every pound of coal to be burned under the boilers must be hauled to the power house. Or, it might fall in a place where it would be difficult to get water for the boilers and the condensers; such a place would, of course, be out of the question. Finally, the question of land comes in. It would be very poor engineering to build a power house in a part of a city where a city building would probably pay as good dividends as many well-managed roads. The final selection of a site for the power house must, in many cases, be a compromise between conflicting conditions. Load conditions will point to one site; good, cheap water will point to another; the coal bunkers should be arranged so that the coal may be passed directly to them from the boat, or from a coal car that can be run alongside of them by means of a siding or a spur from the main line.

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## DETERMINING THE LOAD CENTER

**35.** In the following method used for obtaining the load center, it is assumed that in all cases the layout of the road is along the lines shown in the diagrams, and that there are no limitations imposed by coal, water, and property requirements, the selection of a site for the power house resolving itself to the determination of the load center. To find the load center, the engineer must have a knowledge of the traversed district. With this in hand, the problem can be treated graphically, and amounts to the same thing as finding the center of gravity of a system of bodies. As an example, in Fig. 20, $W$ and $W'$ are two bodies whose centers are

11 feet apart, and each of which, for example, weighs 20 pounds. Since, in this case, the two weights are equal, the distance of their centers from the center of gravity $P$ must also be equal, in order that $W l$ shall equal $W' l'$. The


FIG. 20

center of gravity is, therefore, midway between the two bodies, and the system, as a unit, acts the same as if a weight of 40 pounds were fixed at $P$.

**36.** Where the load is supposed to be uniform over the two sections $A B$ and $A C$, Fig. 19, suppose that there are 10 cars on each section and that each car averages a load of 20 horsepower. Each section will, then, carry a load of 200 horsepower, which can be taken as concentrated at points $O$ and $O'$ in the center of the respective sections. These centers will be $\frac{1}{2} A B + \frac{1}{2} A C$, or 5 miles apart. The two loads of 200 horsepower concentrated at $O$ and $O'$ in Fig. 19 correspond to the two weights of 20 pounds in Fig. 20, and if we treat the 200 horsepower as weights and find their center of gravity, it will be the center of load or the correct location for the power house. Since the two loads or weights are equal, the center of gravity or load must be at point $A$, midway between $O$ and $O'$.

**37.** Take the case shown in Fig. 21, where $W = 40$ pounds, $W'' = 50$ pounds, and $W''' = 10$ pounds; further, suppose that the distance from $W$ to $W''$ is 6 miles; from $W$ to $W'''$, 7 miles; and from $W''$ to $W'''$, 4 miles. Where is the center of gravity situated? First find the center of gravity between weights $W = 40$ and $W''' = 10$, where the distance between centers is 7 miles. This distance of 7 miles must be divided into two parts, such that $W l = W''' l'''$, where $l$ and $l'''$ are the distances of $W$ and $W'''$, respectively, from the center of gravity for these two bodies.

To solve the problem graphically, lay out the plan to scale on paper; that is, represent the 7 miles by 7 inches, and so on, and let the sizes of the circles represent the weights, as shown in the diagram. Call $L$ the distance from $W$ to $W''$, and let the distance from $W$ to the center of gravity to be found, be represented by $l$; then the distance of $W''$ from

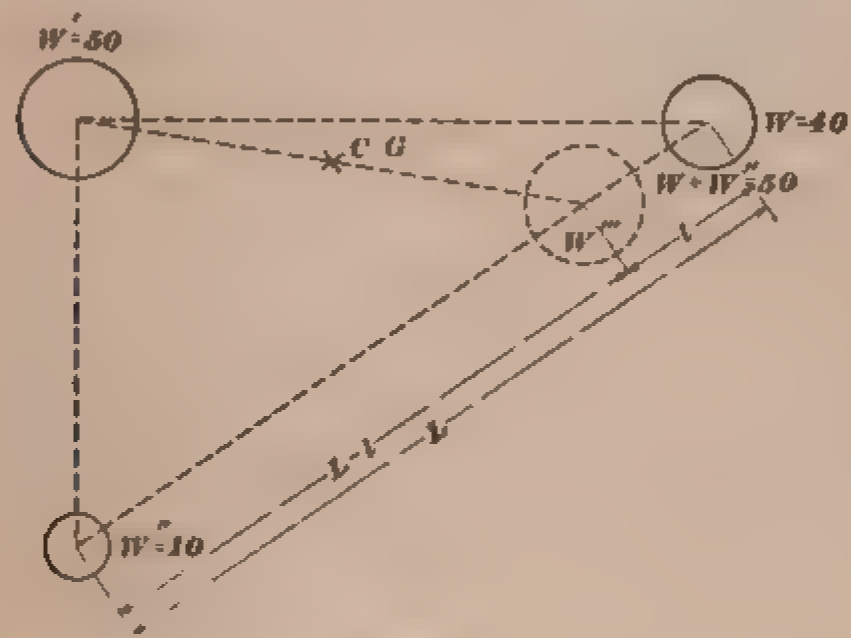



Fig. 21

the center of gravity will be represented by the difference, or $L - l$; and since $Wl = W''(L - l)$, $Wl = W''L - W''l$, or $Wl + W''l = W''L$, and $l = \frac{W''L}{W + W''}$. Substituting for the weights and for $L$ the numerical values given, $l = \frac{10 \times 7}{50} = 1\frac{2}{5}$ miles, or inches on the paper, as the distance of the weight $W$ from the required center of gravity. Since the total distance $L = 7$, the distance from the center of gravity to the center of $W''$ must be $L - l = 5\frac{3}{5}$ miles. On the line joining the centers of $W$ and $W''$ locate a point that is $1\frac{2}{5}$ inches from the center of $W$; this is the center of gravity sought. The center of gravity between the large dotted circle, representing the combined weights (50 pounds) of $W$ and $W''$, situated at their center of gravity, and $W'$, which is also 50 pounds, must now be found. Call the dotted circle $W'''$; since the weights $W'''$ and $W'$ are the

same, it is evident that their center of gravity is midway between them on the line joining their centers, so that it is only necessary to bisect this line in order to find the center of gravity of $W'$ and $W'''$, and hence of the whole system.

**38. Conclusion.**—The general rule for locating the center of load is as follows: Divide the line of the proposed road into several sections; with a knowledge of the service to be rendered on the road, assign a certain load in horsepower, kilowatts, or amperes to each section. Lay out, to scale, a plan of the road on paper and take the load assigned to each section as concentrated at its middle point; there will then be as many of these points as there are sections, and each point will bear a number designating the load on the section of which that point is the center. The numbers can be considered as representing weights and the center of gravity will be the load center that marks the best location for the power house.

## POWER ESTIMATES

**39.** The problem of deciding what capacity the station generators must have in order to operate a given number of cars on a given road is a complex one, in that it involves conditions peculiar to each case and calls for the use of quantities that must, to a great degree, be determined from data relating to roads of a similar character. Among the factors that must be considered are: Weight of equipment; number of cars; speed of cars; topography of the road (grades, curves, etc.); character of traffic; condition of line and rail return; manner of handling the equipment.

The speed at which the cars run is determined largely by the character of the road; cars in cities may not average more than 8 to 12 miles per hour while on interurban roads the average speed might be as high as 40 or 45 miles per hour. The number of cars to be operated depends on the frequency of the service, the length of the line, and the schedule speed. The best schedule speed and frequency of

service for any given road require a close preliminary study of the district to be served, probable traffic and the returns therefrom, competition that must be met, etc.

**40. Weights of Cars.**—The size and weight of cars are determined by the traffic. On interurban lines, cars are much heavier than in cities and frequently they approach, in size and weight, those used on steam roads. A modern 40-foot body interurban car complete with motors and controlling apparatus may weigh as much as 65,000 pounds, whereas a city car with 28-foot body will weigh in the neighborhood of 30,000 pounds. Table I gives approximate weights of

TABLE I

WEIGHTS OF CARS

| Open Cars | | | | | Closed Cars | | | |
|---|---|---|---|---|---|---|---|---|
| Number of Benches | Length Over All Feet | Length Over All Inches | Seating Capacity | Weight of Body and Trucks Pounds | Seating Capacity | Length of Body Feet | Length Over All Feet | Weight of Body and Trucks Pounds |
| 10 | 28 | 8 | 50 | 12,000 | 24 | 18 | 26 | 10,400 |
| 12 | 34 | 0 | 60 | 16,000 | 34 | 25 | 35 | 18,000 |
| 15 | 40 | 4 | 75 | 25,000 | 40 | 28 | 37 | 20,000 |
| | | | | | 44 | 32 | 40 | 28,000 |

ordinary cars of standard size. In designating the length of closed cars, it is customary to measure between outsides of the bulkheads (end walls) and not over the bumpers. The weights given in Table I do not include the motors, controllers, air-brake equipment, etc. The motors will weigh from 45 to 75 pounds per horsepower (railway-motor rating), the weight per horsepower being smaller for large motors than for small ones. An ordinary controller for a 25-horsepower motor will weigh about 200 pounds, and a complete equipment of two such controllers with the starting resistance, about 500 pounds. This is a light equipment such as is used for a small 18- or 20-foot car. For a large car equipped with two 65-horsepower motors, the complete electrical

equipment will weigh about 8,300 pounds, of which the two motors constitute over 7,000 pounds. The auxiliary devices, such as controllers, brakes, etc., vary so much in design that it is difficult to give general figures as to the weight of cars complete with equipment. Ordinary closed cars intended for city service will weigh, roughly, .4 ton per foot of over-all length when fully equipped with motors and all auxiliary appliances. For example, a car with 28-foot body, 37 feet long over all, will weigh, fully equipped, $37 \times .4 = 14.8$ tons. Cars intended for interurban traffic, where the speeds are high, will weigh, fully equipped, from .6 to .7 ton per foot of over all length. In making power estimates, the weight of passengers that should be added to the weight of the car, will not, as a rule, average more than 10 to 15 per cent. of the dead weight of the car.

**41. Formulas for Power Estimates.**—A number of formulas have been devised for calculating the power required by cars under given conditions, but all of them are only approximate, because several elements modify the power taken. For example, the running gear or roadbed may be in bad condition or there may be excessive friction on some of the curves. Again, the state of the weather may have a marked influence on the power required—a strong head-wind may have a very great effect on the resistance offered to the motion of a car; while it is a well-known fact that cars do not run as easily in cold weather as in warm, because of the increased friction at the journals. As a consequence of all these influences, the effects of which cannot be accurately determined, formulas in which the resistance offered to the motion of a car or train is used must not be expected to give results other than approximate.

**42. Force Required to Move Car on Level Track.**—The force or horizontal effort at the rail head, per ton weight, required to move a trolley car on a level track at a uniform speed is considerably higher than required for cars operated on steam roads, where the track is cleaner and in better condition generally. Steam cars are also much

heavier than ordinary street cars and the effort per ton is less for heavy cars than for light ones.

The effort that must be applied to keep a car in uniform motion on a level track depends on the train resistance at uniform speed and this, in turn, is made up of a number of factors that are more or less difficult to determine and which vary, to a certain extent, with the speed. For example, the train resistance includes the track friction, or the resistance that the wheels encounter in rolling over the slight irregularities in the surface of the track, the friction in the journals, friction of wheel flanges against the rails, air resistance, etc.

If $f$ = resistance, in pounds, per ton on a level track, i. e., horizontal effort at rail head for each ton that the car weighs;

$W_t$ = weight of car, in tons;

$F$ = total pull required;

then,

$$F = f W_t \qquad (1)$$

The case of cars operating at moderate speeds in cities, where the effort per ton may be taken as constant for all speeds at which the cars usually run, will first be considered. For ordinary cases, with cars and track in good condition, a fair average value for $f$ on a level track is 20 pounds.

**43. Effect of Grades.**—Grades are always expressed as a percentage, but there seems to be considerable confusion as to what this percentage refers. In some cases it relates to the distance actually traveled by the car in ascending the grade; in others, to the horizontal distance. The more general method in dealing with electric railways is to consider the percentage as referring to the actual distance traveled by the car, and it will be so taken in the following calculations. Thus, if a grade is said to be 3 per cent. it means that for every 100 feet traveled along the grade the car rises 3 feet. This simplifies calculations and, as a matter of fact, unless grades are much steeper than those usually met with in practice it makes very little difference, so far as numerical results are concerned, which is taken

because the distance traveled along the grade is practically the same as the horizontal distance.

When a car ascends a grade, the force exerted, in addition to overcoming the various resistances, must be sufficient to lift the weight of the car. Thus, on a 1-per-cent grade, the car rises 1 foot for every 100 feet traveled. This is equivalent to lifting the weight of the car one one-hundredth of the distance or lifting one one-hundredth of the weight the whole distance. In other words, for each ton (2,000 pounds) that the car weighs, each per cent. grade is equivalent to the addition of $\frac{2,000}{100} = 20$ pounds to the effort required on the level, and

$$f_g = f + 20\,G \qquad (2)$$

where $f_g$ = pounds per ton on the grade;
$f$ = pounds per ton on the level;
$G$ = per cent. grade.

EXAMPLE.—If 20 pounds per ton is required to maintain uniform motion of a 10-ton car on a level track, what effort, per ton, will be required on a 5-per-cent. grade?

SOLUTION.—For each per cent. of grade, the force must be increased 20 lb. per ton over the amount required on the level; hence, $f_g = 20 + 20 \times 5 = 120$ lb. per ton. Ans.

**44. Horsepower.**—When the total force $F$, in pounds, and the speed $S$, in miles per hour, are known the horsepower can at once be calculated as follows:

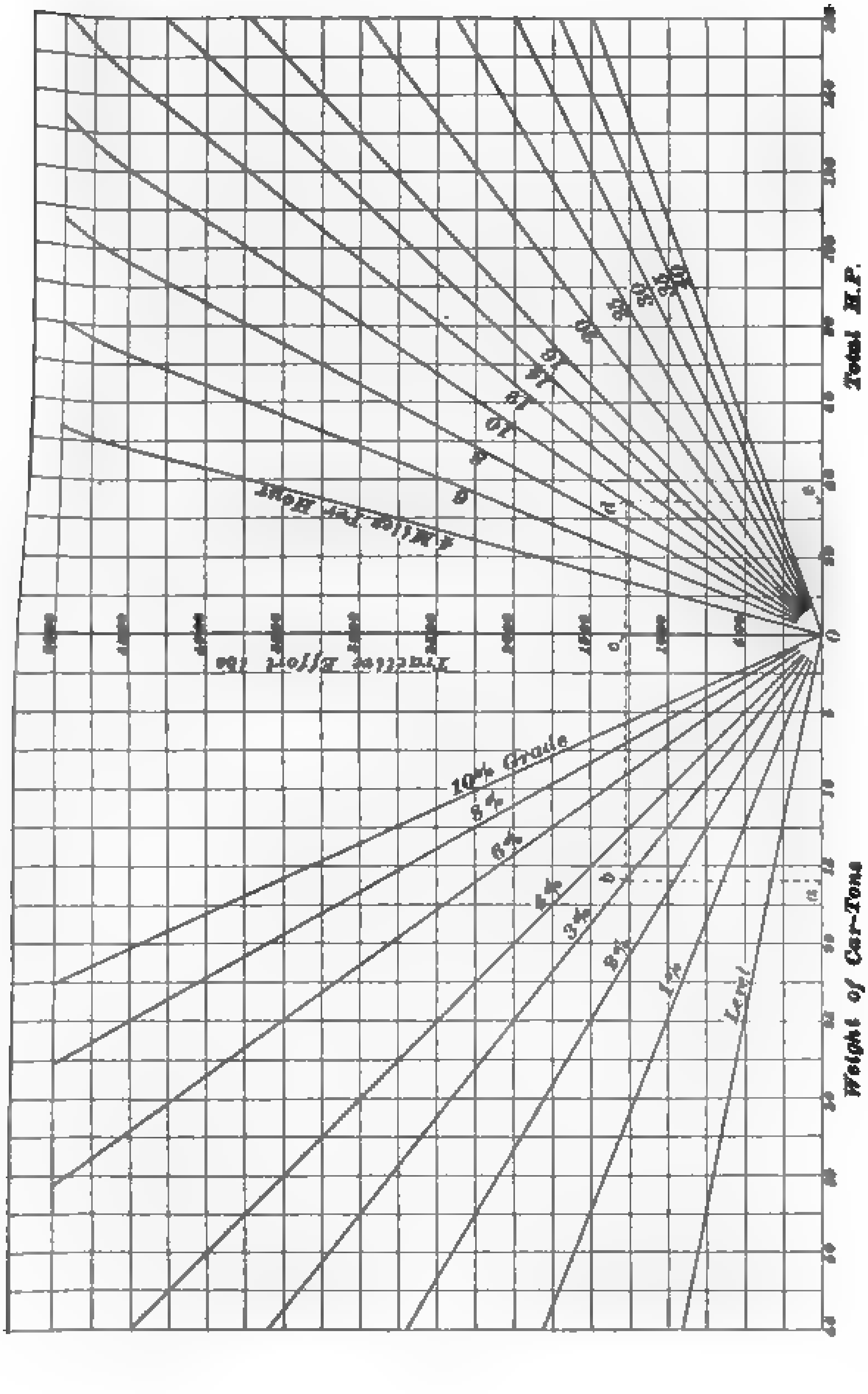
$$\text{Speed, in feet per minute} = \frac{5{,}280\,S}{60}$$

$$\text{horsepower} = \frac{\text{foot-pounds per minute}}{33{,}000} = \frac{5{,}280\,S\,F}{60 \times 33{,}000}$$

or,
$$\text{horsepower} = \frac{S\,F}{375} \qquad (3)$$

If the car is moving up a grade, $F$ must, of course, include the effort necessary to lift the car. This formula gives the horsepower actually used in moving the car; the electrical power supplied will be somewhat greater on account of the electrical losses in the motors and controlling apparatus.

**45.** The curves shown in Fig. 22 are useful in making approximate determinations of the tractive effort and


Total H.P.
Weight of Car-Tons
Tractive Effort lbs
Miles per Hour
10% Grade
8%
6%
4%
3%
2%
1%
Level

horsepower required under given conditions. They are given by the Westinghouse Company and are based on the assumption that the tractive effort per ton on the level is 20 pounds, and 20 pounds additional for each per cent. grade.

EXAMPLE.—How many horsepower are required to move a car weighing 16 tons up a 3-per-cent. grade at the rate of 10 miles per hour, if the tractive effort is 20 pounds per ton on the level?

SOLUTION.—The tractive effort will be from formula **2**, $f_r = 20 + 20 \times 3 = 80$ lb. per ton and the total tractive effort $F = 16 \times 80 = 1{,}280$ lb. The speed $S$ is 10 mi. per hr., hence, from formula **3**,

$$\text{H. P.} = \frac{10 \times 1{,}280}{375} = 34.1. \quad \text{Ans.}$$

The problem can be solved more rapidly by referring to Fig. 22. First find the point $a$ on a horizontal line to the left of $O$, corresponding to 16 tons; draw a vertical line at $a$ until it intersects the 3-per-cent. line at $b$. The height of this line will represent the total tractive effort that can be read off the central vertical scale by drawing a horizontal line across from the intersection $b$ to $c$. Continue this horizontal until it intersects the speed line corresponding to 10 miles per hour at point $d$ and drop a perpendicular on the base or $H. P.$ line from $d$; $Oe$ represents the horsepower required and is read off the horizontal scale, giving 34.1 horsepower, as calculated.

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## TRAIN ACCELERATION

**46.** So far it has been assumed that the motion of the cars was uniform. It requires, however, much more power to start a train and get it under headway than to keep it in motion after it has been started. If cars were equipped with motors having a capacity based on calculations relating to uniform motion, they would be too small unless the conditions were such that the stops were very infrequent. In the early days of electric railroading, the motors installed were soon found to be too small, largely because the excess of power required at starting had been overlooked.

**47.** In order to start a train from rest and bring it up to speed, a certain amount of energy must be expended over and above that necessary to overcome the train resistance. The energy so expended is stored in the train as

kinetic energy. A powerful effort is necessary to accelerate the train, and the effort required in any given case will depend on the weight of the train and the acceleration. In problems connected with train operation, the rate at which the speed of a train is increased (acceleration) or decreased (retardation, or deceleration, as it is sometimes called) is expressed in miles per hour per second. For example, if the acceleration is $1\frac{1}{4}$ miles per hour per second, it means that in each second the speed of the train is increased $1\frac{1}{4}$ miles per

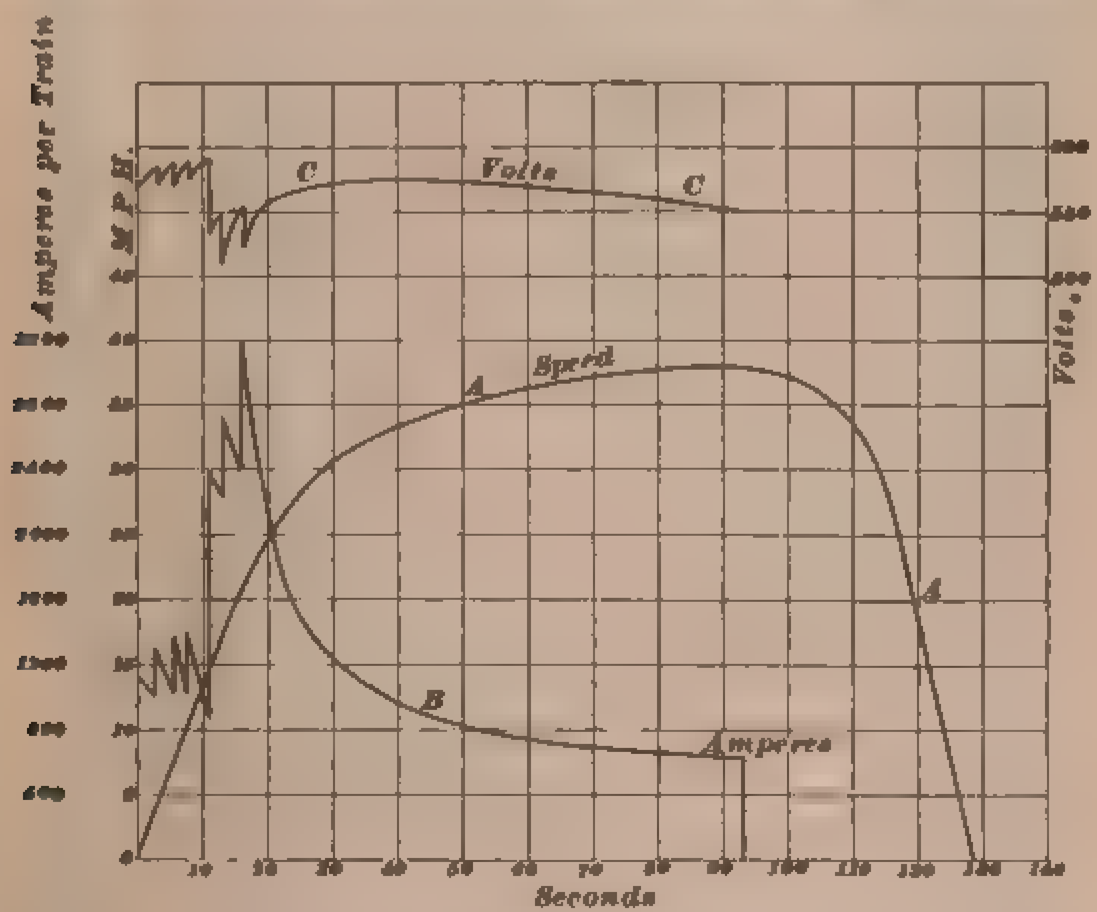


Fig. 23

hour. If the train started from rest, at the end of the first second it would be moving at the rate of $1\frac{1}{4}$ miles per hour, at the end of the second second, at $2\frac{1}{2}$ miles per hour, and so on.

Fig. 23 shows typical curves for an electric train with powerful equipment capable of producing rapid acceleration. Curve *A* shows the relation between speed and time; *B*, shows the total current supplied; and *C*, the voltage. Starting from a standstill, the speed increases at an almost uniform rate up to 25 miles per hour, the curve then bends over and

the increase in speed during a given interval of time, i. e., the acceleration, becomes less until at $37\frac{1}{2}$ miles per hour the curve has become nearly horizontal; the speed is then nearly uniform and the acceleration has become practically zero. After 93 seconds the current is shut off and the train coasts along, by virtue of the energy stored in it, with gradually decreasing speed. The brakes are applied at the latter end of the run and the train is retarded and finally brought to a stop, as indicated by the straight sloping line at the right. When the train is started with all the starting resistance in series, the total current is about 1,100 amperes, and as the resistance is cut out, the current varies, as shown by the notches in the curve during the first 10 seconds; the motors are then thrown in parallel and the total current rises to nearly 2,400 amperes, after which it further increases to 3,200 amperes, as the resistance on the parallel notches is cut out. Up to this point the current in each motor has remained approximately constant and the tractive effort has, therefore, been nearly constant. The train resistance is also approximately constant for moderate speeds with the net result that the speed is almost uniformly accelerated from 0 to 25 miles per hour during the first 20 seconds. The average acceleration during this interval is 1.25 miles per hour per second. As the speed increases beyond 25 miles per hour, the current rapidly diminishes and the tractive effort also diminishes. The acceleration therefore decreases, and when the current has dropped to about 650 amperes the speed has become nearly uniform. The tractive effort is then wholly utilized in overcoming the train resistance; during the acceleration period a large part of the total effort was used in increasing the speed and thereby storing energy in the train, and the remainder went to overcome the train resistance.

**48. Force Required for Acceleration.**—The total force $F_a$ required to make a car or train increase its rate of speed is easily calculated; it is $F_a = m\,a$, where $m$ is the mass of the train and $a$ the acceleration. $m = \frac{w}{g}$, where $w$

is the weight of the train and $g$ the acceleration due to gravity; hence, $F_a = \frac{w}{g}a$. If $w$ is expressed in pounds, $g$ in feet per second per second, and $a$ in feet per second per second, then $F_a$ will be in pounds and $F_a = \frac{w}{32.16}a$, since $g$ is equal to 32.16 feet per second per second. Usually, in train calculations, the weight is expressed in tons and the acceleration in miles per hour per second instead of feet per second per second. One mile per hour = 1.467 feet per second and 1 ton = 2,000 pounds. If, then, $A$ is the acceleration in miles per hour per second, the number of feet per second per second will be 1.467 $A$, and if $W_t$ is the weight in tons, the number of pounds will be 2,000 $W_t$. The equation will then become $F_a = \frac{2{,}000\ W_t}{32.16} \times 1.467\ A$, or

$$F_a = \frac{W_t A}{.01097} = 91.2\ W_t A \qquad (4)$$

EXAMPLE.—If an electric car weighs 20 tons, what accelerating force must be exerted to bring the car from a standstill up to a speed of 18 miles an hour in 15 seconds, assuming the acceleration to be uniform during this period?

SOLUTION.—The acceleration $A$ is $\frac{18}{15}$ = 1.2 mi. per hr. per sec. $W_t$ = 20 tons; hence, from formula 4,

$$F_a = 91.2\ W_t A = 91.2 \times 20 \times 1.2 = 2{,}188.8 \text{ lb.} \quad \text{Ans.}$$

From formula 4, the tractive effort necessary to produce an acceleration of 1 mile per hour per second is 91.2 pounds for each ton weight of car. Fig. 24 shows the relation between the acceleration, in miles per hour per second, and the accelerating force, in pounds per ton. It must be remembered that this is in addition to the force required to overcome the train resistance. Again, whenever a train is started there are two kinds of inertia to be overcome: The train must be made to move horizontally and the force required for this acceleration is given by formula 4; also, a certain amount of energy is required to overcome the inertia of the rotating parts, such as armatures, wheels, gears, and axles, and this may amount to 8 or 10 per cent. of the force

given by the formula. The force required to overcome train resistance may be taken as 20 pounds per ton for moderate speeds on a good track, and if the force required to produce acceleration both rotational and linear is 100 pounds per ton for an acceleration of 1 mile per hour per second, the total tractive effort required to speed up the car at this rate will not be far from 120 pounds per ton.

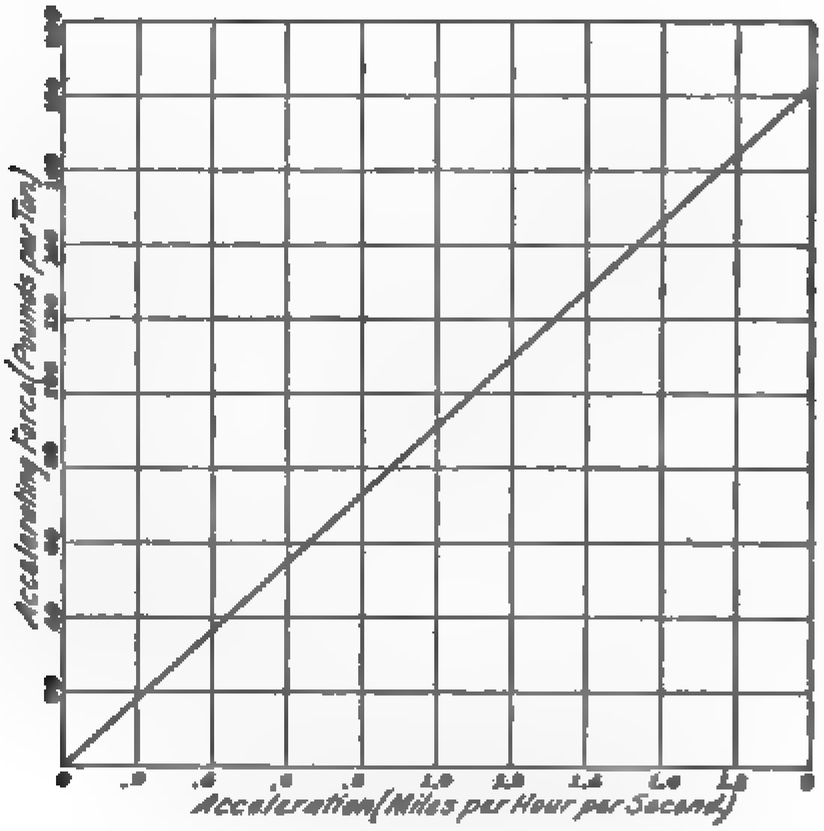


FIG 24

In city streets, where the speed is limited, it is not necessary or even desirable to accelerate the cars rapidly, but in elevated or underground service, where a large number of trains must be operated at close intervals, they must be started quickly, and the size of the motors will be determined very largely by the energy required for acceleration.

**49. Limit of Adhesion.**—The maximum effort at the rail head that can be applied to a car is limited by the slippage of the wheels on the track; as is also the possible acceleration and the grade that a car can ascend. The adhesion between wheels and track depends on the weight on the drivers and the coefficient of friction between the

wheels and track. The latter varies greatly with the condition of the rails, being considerably lower for street-car lines where the tracks are liable to be dirty and slippery than for elevated, undergound, or interurban roads where the tracks are cleaner. It also depends on the kind of car wheels, being considerably less for wheels with chilled-iron treads than for those with steel tires. As safe limiting values, the adhesive force may be taken as about 15 per cent. of the weight on the drivers for elevated or interurban roads, and 12 per cent. for street-car roads. Thus, on street-car lines, the maximum tractive effort that can be exerted without causing wheel slippage may be taken as $2,000 \times .12 = 240$ pounds per ton weight on the driving wheels and $2,000 \times .15 = 300$ pounds for elevated or interurban roads. It should be particularly noted that these limiting tractive efforts are per ton weight on the driving wheels. With a small single-truck street car having two motors, all wheels are drivers and the whole weight rests on driving wheels; hence, this style of car is well adapted for hill climbing and running on slippery tracks. With interurban or elevated cars having double trucks and two motors, the weight resting on the drivers will not be more than 55 to 70 per cent. of the total weight, thus making the limiting tractive effort from 165 to 210 pounds per ton weight of car. With cars having double trucks with four motors, one on each axle, the whole of the weight is on drivers; hence, four-motor equipments are desirable for roads operating double-truck cars in hilly localities. For interurban roads, the grades are usually quite moderate and two-motor equipments give sufficient adhesion.

Let $f' =$ force, in pounds per ton weight of car to start car on level;

$G =$ grade expressed as percentage;

$W_t =$ weight of car, in tons;

$a =$ percentage of weight on drivers, expressed as a decimal;

$b =$ ratio of adhesive force to weight on drivers expressed as a decimal.

Then,

Total weight on drivers, in pounds . . . $= 2{,}000\ a\ W_t$

Total adhesive force . . . . . . $= 2{,}000\ a\ W_t\ b$

Total force required for starting on grade $G = f'\ W_t + 20\ G\ W_t$

Each per cent. grade requires 20 pounds per ton additional effort. When the grade is such that the tractive effort required to start on it is just sufficient to produce wheel slippage, we must have $2{,}000\ a\ W_t\ b = f'\ W_t + 20\ G\ W_t$, and

$$G = \frac{2{,}000\ a\ W_t\ b - f'\ W_t}{20\ W_t} = \frac{2{,}000\ a\ b - f'}{20} \qquad (5)$$

About 70 pounds per ton is a fair value for the effort $f'$ required to start a car on the level under ordinary conditions; if, however, the acceleration is very rapid, the effort during the time that the car is gaining headway may be much higher than this and the acceleration obtainable may therefore be limited by the wheel slippage.

EXAMPLE.—If 65 per cent. of the weight of a car rests on the drivers and if the ratio of the adhesive force to the weight on the drivers is 15 per cent. what is the maximum grade that the car can start on without wheel slippage, assuming that it requires an effort of 70 pounds per ton weight of car to start the car on the level?

SOLUTION.—Using formula 5, we have $a = .65$, $b = .15$, and $f' = 70$; hence, $G = \frac{2{,}000 \times .65 \times .15 - 70}{20} = 6.25$; i. e., slippage will occur if the grade exceeds 6.25 per cent. Ans.

## TRAIN RESISTANCE

**50.** In all that has so far been said regarding power calculations, the tractive effort has been taken as 20 pounds per ton regardless of the speed, weight, or shape of the cars. This gives fairly close results for light single cars operated at moderate speeds, under the conditions usually met in city streets, but for heavy single cars or trains operated at high speeds, as used in the heavier kinds of electric traction, it is not safe to assume a fixed value for the train resistance. At low speeds and with heavy cars the effort per ton may be considerably under 20 pounds, and at high speeds it will be greater.

The subject of **train resistance** is a complicated one, because the resistance depends on a number of quantities, which vary more or less with the speed. The air friction increases approximately as the square of the speed and is dependent in a large measure on the shape of the front of the cars and on the area of the exposed surface. On account of the difficulty of determining the amount of the different resistances and their relation to the speed of the train, no formula has yet been established for calculating the tractive effort that must be exerted to move electric trains under widely varying conditions; and from the nature of the case, it is doubtful if any generally applicable formula can be obtained. A number of formulas have been devised that are reasonably accurate, provided that their use is limited to cases where the conditions correspond to those existing during the tests on which the formulas are based. The object here is simply to point out two or three formulas that have been proposed and to show, to some extent, the quantities on which the resistance depends and the amount of resistance due to each. Formula **6**, given below, is due to Mr. W. N. Smith,* and has been found to give results that agree quite closely with tests made on cars weighing from 28 to 32 tons operating at schedule speeds varying from 16 to 35 miles per hour, the maximum speeds during the runs varying from about 27 to 44 miles per hour. The formula is

$$f = 3 + .167\,S + .0025\,\frac{A\,S^2}{W_t} \qquad \textbf{(6)}$$

where $f$ = train resistance, in pounds per ton;
$S$ = speed, in miles per hour;
$A$ = cross-section of car, in square feet;
$W_t$ = weight of car, in tons.

For example, the resistance offered to a 40-ton train moving at the rate of 30 miles per hour and having a cross-sectional area of 100 square feet would be $f = 3 + .167 \times 30$

*Transactions American Institute of Electrical Engineers, Vol. XXI, No. 10.

$+ .0025 \times \frac{100 \times 30^2}{40} = 13.64$ pounds per ton. With heavy trains, the train resistance per ton weight of train is less than with light trains.

**51.** As an example of the resistance of electric trains obtained from actual tests, the experiments of Wm. W. J. Davis* may be cited. These were made with a 37-ton electric locomotive hauling passenger cars of standard type weighing 25, 35, and 45 tons. The number of cars per train was varied from 1 to 5, and the influence of the size of the cars and the weight of the train on the resistance per ton could thus be noted. The curves in Fig. 25 give the results obtained with 25-ton cars; those in Fig. 26 the results obtained with 45-ton cars; these show that the resistance per ton weight is much greater with light than with heavy trains. In Fig. 25, a single-car train at 60 miles per hour offers a resistance of about $58\frac{3}{4}$ pounds per ton, whereas, with a two-car train at the same speed, the resistance is but 39 pounds per ton. The journal friction in case of the 25-ton cars is 8 pounds per ton for all speeds; with the 45-ton cars, the journal friction is 5 pounds per ton. In Figs. 25 and 26, the constant journal friction is represented by the vertical dotted line. The friction due to unevenness in the track is taken proportional to the speed, and in these tests was found to be

$$f' = .13\,S \qquad (7)$$

where $f'$ = track friction;

$S$ = speed, in miles per hour.

The track friction is represented by the slanting dotted lines. That is, the distance between the vertical dotted line and the track-friction line at any given speed represents the track friction at that speed, and the distance between the track-friction line and the vertical passing through $O$ represents the journal friction and track friction combined.

*Street Railway Journal, Vol. XIX, No. 18.

At a speed of 35 miles per hour, the track friction would be $f' = .13 \times 35 = 4.55$ pounds per ton. Hence, the distance between the two dotted lines at the point corresponding to a speed of 35 miles per hour is equivalent to

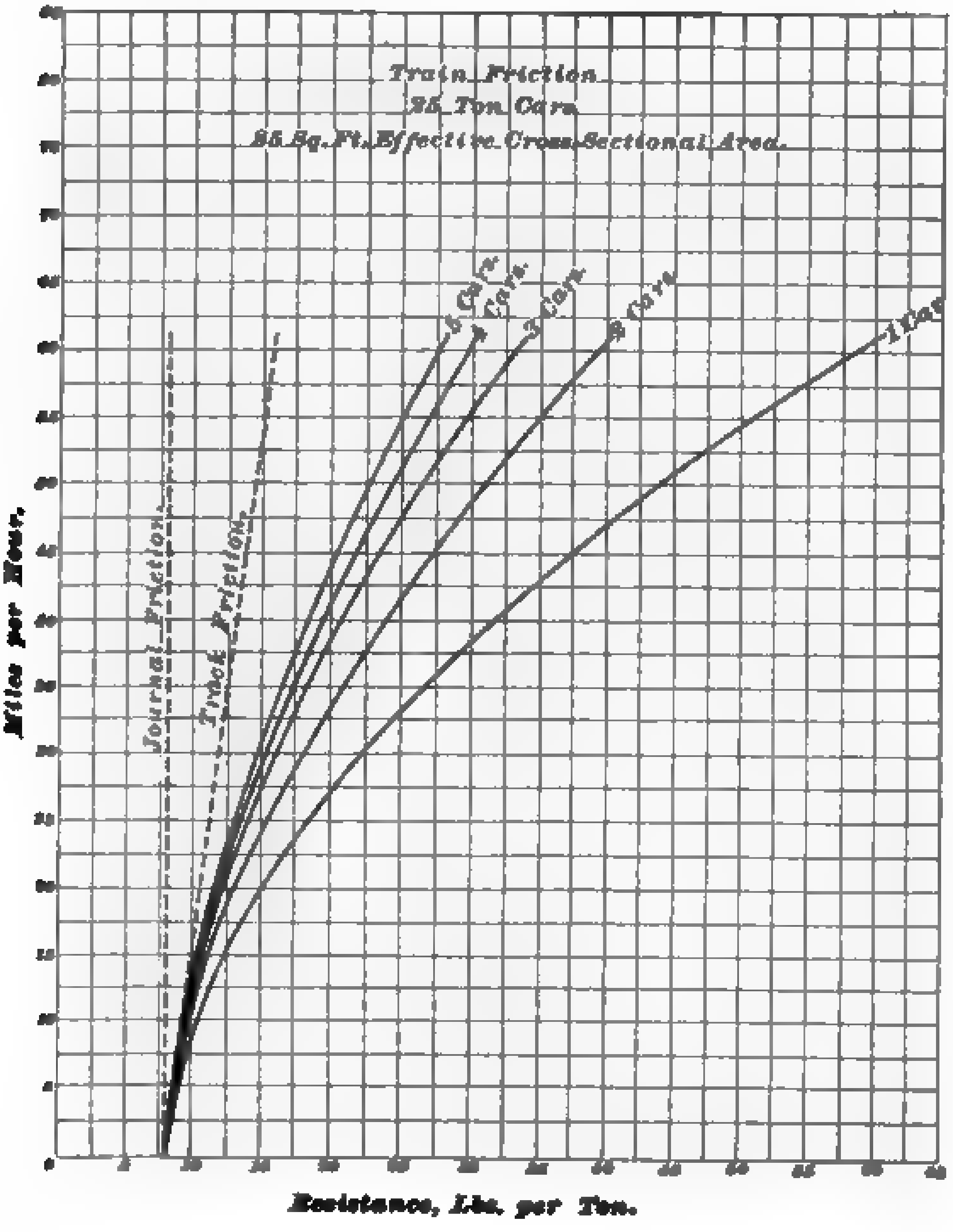


FIG. 25

4.55 pounds per ton. The full-line curves represent the total resistance per ton for trains of 1, 2, 3, 4, and 5 cars. The horizontal distance between the dotted slanting line and

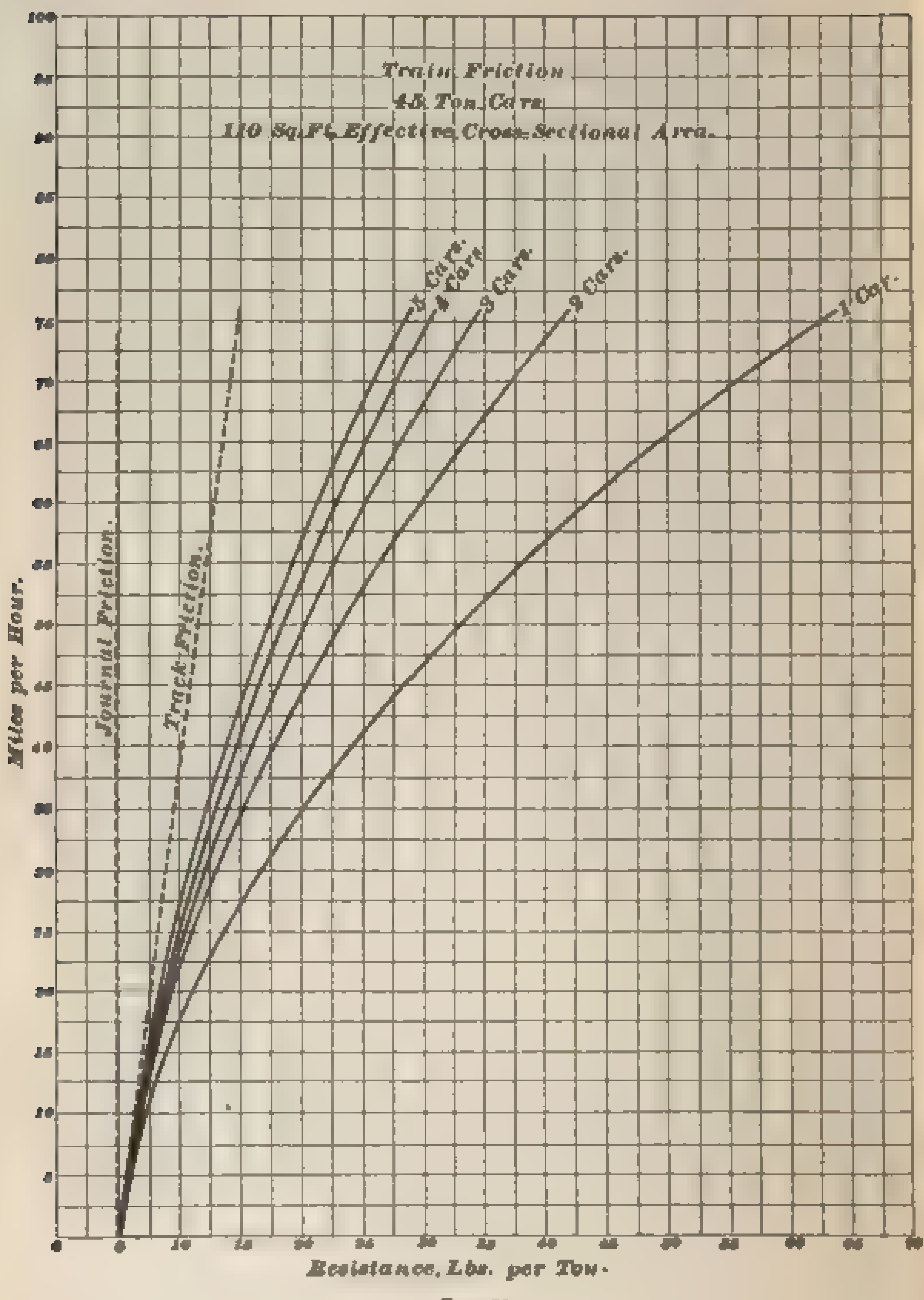
Train Friction
45 Ton Cars
110 Sq. Ft. Effective Cross-Sectional Area.
5 Cars.
4 Cars.
3 Cars.
2 Cars.
1 Car.
Journal Friction.
Track Friction.
Miles per Hour.
Resistance, Lbs. per Ton.

FIG. 26

the curved lines represents the air resistance for trains made up of different numbers of cars. With a single-car train at a speed of 35 miles per hour, the air friction is nearly 16 pounds per ton, and the resistance increases rapidly with increasing speeds. The effect of air resistance is not as pronounced with heavy trains as with light trains. These experiments indicate that it is more economical, as regards power consumption, to operate the cars in trains than singly, especially at high speeds.

**52.** From these experiments Mr. Davis has derived the following formulas for obtaining the tractive effort for heavy electric trains:

For 25-ton cars having a cross-sectional area of about 85 square feet,

$$f = 8 + .13\,S + \frac{.0035\,A\,S^2}{W_t}[1 + .1(n - 1)] \qquad (8)$$

For 45-ton cars having a cross-sectional area of about 110 square feet,

$$f = 5 + .13\,S + \frac{.0035\,A\,S^2}{W_t}[1 + .1(n - 1)] \qquad (9)$$

where $f$ = train resistance, in pounds per ton;
$S$ = speed, in miles per hour;
$A$ = cross-sectional area of car, in square feet, including area bounded by wheels and truck;
$W_t$ = total weight of train, in tons;
$n$ = number of cars in train including leading car or locomotive, if an electric locomotive is used.

In formula **6**, the constant journal friction is taken at 3 pounds per ton; this is rather low for light cars, being less than half that shown by the Davis tests for 25-ton cars. Formula **6** is, however, intended chiefly for calculations relating to heavy cars.

## POWER CONSUMPTION TESTS

### INTERURBAN ROADS

**53.** Tests made on cars in every-day operation afford the most reliable means of estimating the probable amount of power required for a given service. Such tests include observations of the power, speed, time, voltage, current, grades, curves, etc.; in fact, everything that is liable to influence the power consumption. Some very elaborate tests of this character have been made and with regard to interurban roads one of the most complete is that conducted by Mr. Clarence Renshaw on the system of the Union Traction Company, of Indiana.* The figures here given relate to tests made on this road with cars having 40-foot bodies, weighing 63,000 pounds, and equipped with two 150-horsepower motors mounted on the forward truck. The power consumption was measured for both limited and local service so that the effect of stops could be determined. In local service, the average speed for the whole run, 56.5 miles, was 22.6 miles per hour, but part of the run was through cities where the speed had to be reduced. Outside the cities, the speed on local service averaged 26.6 miles per hour. In limited service, the cars averaged 28.3 miles per hour for the whole run and 35.3 miles per hour leaving out the slow running in the cities. The speed between stations frequently rose to 40 and 45 miles per hour, and on one part of the road reached 60 miles per hour. Most of the grades were less than 2 per cent., but a few short ones were as high as 3 per cent. The weight of the car with passengers varied on the different trips, but was usually from 34 to 34.5 tons. The power consumption, as indicated by the average of a large number of wattmeter readings, is given in Table II.

From these figures, it would be safe, in making a preliminary estimate on a road of the same general character as this, to allow from 70 to 75 watt-hours per ton-mile for

*Street Railway Journal, Vol. XX, No. 14.

limited service and 85 to 90 watt-hours per ton-mile for local service.

It is interesting to note that very complete tests made with 25-ton cars on a different interurban road—the Dayton and Northern Traction Company—give results that agree quite closely with those in Table II. The average power consumption for a number of regular trips with the speed varying from 8 to 29 miles per hour, was 2.16 kilowatt-hours per car mile or 86.4 watt-hours per ton-mile. The average consumption for a number of test runs, with speeds varying from 19 to 27.5 miles per hour, was 1.96 kilowatt-hours per car mile or 78.4 watt-hours per ton-mile. The greatest power consumption was for a short run of 1.46 miles at the slow speed of 8 miles per hour, when the consumption was 148 watt-hours per ton-mile.

TABLE II

POWER CONSUMPTION OF CARS

*(Interurban Road)*

| Class of Service | Kilowatt-Hours per Car Mile | Watt-Hours per Ton-Mile |
|---|---|---|
| Local service, outgoing trips | 2.24 to 2.78 | 66.7 to 81 |
| Local service, return trips | 2.62 to 2.31 | 77 to 89.5 |
| Local service, average for six round trips | 2.62 | 76.6 |
| Limited service, outgoing trips | 2.1 | 58.7 |
| Limited service, return trips | 2.31 | 71.6 |

54. **Influence of Stops.**—It seems strange at first glance that the slow-speed local service (Table II) should show a power consumption greater than that of the high-speed limited service, but the explanation is found in the relatively large number of stops necessitated by the local service. Every time a car is started, a certain amount of energy is wasted in the starting resistance and energy is also required for acceleration. The greater part of the latter is usually wasted at the brake shoes when the car is brought to a stop. Thus, if the stops are very numerous the power

consumption per ton-mile is considerably increased. Tests on the Union Traction Company's road showed that, on the average, the local service required 15 per cent. more power per trip than the limited service.

The following comparison of a number of runs shows clearly the increased power consumption due to stops.

| Service | Stops | Watt-Hours per Ton-Mile | Time for Trip | |
|---|---|---|---|---|
| | | | Hours | Minutes |
| Limited . . . | 4 | 71.6 | 2 | |
| Local . . . . | 31 | 83.3 | 2 | 36 |
| Local . . . . | 44 | 89.5 | 2 | 53 |

It must not be inferred that in all cases local service with numerous stops requires more power than high-speed service with few stops; in fact, the contrary is often the case. In this instance the schedule speed on limited service is not very high (35.3 miles per hour), but with higher schedule speed the energy per ton-mile for limited service would be greater than that for local service and might easily be from 90 to 110 watt-hours. When the average speed is over 35 miles per hour a comparatively slight increase in speed involves a large increase in power because of the great increase in air resistance.

**55. Current.**—In the above tests, the cars took at starting from 200 to 250 amperes and when the motors were placed in parallel the current rose as high as 250 to 330 amperes. These large currents, however, only lasted for short intervals.

**56. Voltage.**—The average line voltage, when the car was running, was 454 volts, but the average voltage at the terminals of the motors was very much lower because sometimes the motors were in series, with resistance, sometimes in series without resistance, or in some cases no voltage at all was applied to them, as, for example, when the car was

coasting or when the brakes were applied. The average voltage per motor was thus about 237 volts.

**57. Conclusion.**—The application of the data here given can best be illustrated by working an example.

EXAMPLE.—An interurban electric road is to operate ten cars weighing 30 tons each when loaded. Six of these are to run on local service and four on limited service, the average speed on local service being 20 miles per hour and on limited service 32 miles per hour. Estimate the approximate capacity of the generating plant, assuming that the total loss between generators and cars is 18 per cent. of the delivered power.

SOLUTION.—Referring to the figures given in Art. **53**, the average power consumption, in watt-hours per ton-mile, may be taken at, say, 72.5, taking the average of 75 and 80 for the limited cars, and 87.5 for the local service. In 1 hr., therefore, the total number of watt-hours supplied would be:

| | | |
|---|---|---|
| For local service, | $6 \times 30 \times 20 \times 87.5 =$ | 315,000 watt-hours |
| For limited service, | $4 \times 30 \times 32 \times 72.5 =$ | 278,400 watt-hours |
| | Total, | 593,400 watt-hours. |

Since the energy supplied to the cars in 1 hr. is 593,400 watt-hours it follows that the power is 593,400 watts, or 593.4 K. W. The loss between the generating station and the cars is $593.4 \times .18 = 106.8$ K. W. This represents the loss in lines, third rail, rotary converters, and transformers. The average output of the station will therefore be $593.4 + 106.8 = 700.2$ K. W. On an interurban system, where comparatively few cars are operated, the fluctuations in load are very great and the maximum load is usually from 1.5 to 2 times the average load. Also, considerable power is required for lighting and heating cars and lighting stations. In this case, therefore, the machinery should be capable of furnishing at least 1,000 K. W., and in order to insure against shut-downs it would be advisable to install two generating units of 1,000 K. W. each, or at least three generators of 500 K. W. each, two being operated in parallel under ordinary conditions and the third kept as a reserve. Ans.

## CITY ROADS

**58.** The power consumption per ton-mile is greater for city roads than for interurban lines. The cars are lighter and the tractive effort per ton greater, the stops are much more frequent, and in most cases the track is not as clean or in as good condition. Also on account of the slow speed and numerous stops, considerable power is wasted in the

## TABLE III

### POWER CONSUMPTION OF CARS

*(City Road)*

| Type of Motor | Horsepower of Each Motor (Railway Rating) | Number of Motors per Car | Average Current Amperes | Maximum Current Amperes | Average Pressure Volts | Average Watts | Watt-Hours per Car Mile |
|---|---|---|---|---|---|---|---|
| Westinghouse, No. 3 | 30 | 1 | 13.3 | 60 | 538 | 7,155 | 812 |
| Westinghouse, No. 3 | 30 | 1 | 26.0 | 60 | 519 | 13,494 | 1,180 |
| Westinghouse, No. 3 | 30 | 2 | 37.7 | 160 | 470 | 17,719 | 1,690 |
| Westinghouse, No. 3 | 30 | 2 | 30.6 | 125 | 470 | 14,382 | 1,249 |
| Westinghouse, No. 3 | 30 | 2 | 20.3 | 80 | 470 | 9,541 | 864 |
| Westinghouse, No. 3 | 30 | 2 | 17.0 | 72 | 474 | 8,058 | 690 |
| Westinghouse, No. 3 | 30 | 2 | 17.8 | 65 | 488 | 8,686 | 781 |
| Westinghouse, No. 3 | 30 | 2 | 18.0 | 88 | 494 | 8,892 | 804 |
| Westinghouse, No. 3 | 30 | 2 | 20.1 | 75 | 498 | 10,010 | 1,062 |
| Westinghouse, No. 3 | 30 | 2 | 17.3 | 70 | 519 | 8,979 | 814 |
| Westinghouse, No. 3 | 30 | 4 | 38.9 | 175 | 486 | 18,905 | 1,636 |
| Westinghouse, No. 3 | 30 | 4 | 41.2 | 150 | 446 | 18,375 | 1,895 |
| Westinghouse, No. 49 | 35 | 2 | 34.0 | 125 | 452 | 15,368 | 1,479 |
| Westinghouse, No. 49 | 35 | 2 | 27.0 | 118 | 444 | 11,988 | 1,034 |
| Westinghouse, No. 49 | 35 | 2 | 10.6 | 75 | 494 | 5,236 | 539 |
| Westinghouse, No. 49 | 35 | 2 | 18.7 | 70 | 492 | 9,200 | 798 |
| Westinghouse, No. 49 | 35 | 4 | 43.5 | 170 | 471 | 20,489 | 1,924 |
| Westinghouse, No. 49 | 35 | 4 | 44.8 | 170 | 536 | 24,013 | 2,128 |
| Westinghouse, No. 38 B | 50 | 2 | 50.8 | 185 | 485 | 24,638 | 1,845 |
| Westinghouse, No. 38 B | 50 | 2 | 47.4 | 200 | 478 | 22,657 | 1,845 |
| Westinghouse, No. 56 | 60 | 4 | 110.4 | 420 | 471 | 51,998 | 3,778 |

**EQUIPMENT (**

| | Road | | Number and Size of Cars | | | | | | | Mot | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Kind of Road | Miles of Single Track | Number of Cars | Number of Open Cars | Number of Closed Cars | Size of Open Cars | Length of Closed Cars Over All | Length of Closed Cars Between Bulkheads | Other Rolling Stock in Regular Operation | Number per Car | Type or Horse-… |
| *A* | Inter-urban | 28.25 | 13 | | 6 | | 42 ft. 3 in. | | 1 double-truck work car; 6 single-truck flat cars | 4 | * W… No… |
| *B* | Inter-urban | 90 | 20 | | 20 | | 60 ft. | 50 ft. | | 4 | † G. … 75 … |
| *C* | Small city | 9.16 | 40 | 24 | 15 | | 18 ft. | | 1 combined sprinkler and snow plow | 2 | 3… |
| *D* | City | 116.8 | 268 | | | 9 and 10 bench | | 20 and 21 ft. | | 2 | G. … 38 … |
| *E* | Inter-urban | 39.5 | 8 | | 8 | | 44 ft. 6 in | | 1 freight car, 42 ft long | 4 | 50 … |
| *F* | City | 83 | 122 | [illegible] | 70 | 8 and 10 bench | | 18 ft 20 ft. 28 ft. | | 18 ft. 20 ft. and open cars, 2 motors; 28-ft cars, 4 motors | W. H. … W. H. … W. H. … W. H. … |
| *G* | Inter-urban | 34 | 10 | | 10 | | 45 ft. | | | 4 | G. … |
| *H* | City and sub-urban | 34 | 9 | | 9 | | 6 suburban, 49 ft 5 in | 3 city cars, 18 ft body | | Suburban 4 City 2 | 75 … 25 … |
| *I* | City | 63.37 | 57 | | 57 | | 40 ft. | | 1 electric locomotive | 4 | |
| *J* | Inter-urban | 66.6 | 15 | 3 | 12 | 15 bench | 50 ft. | | 1 35-ton electric locomotive for freight | 4 | 50 … |
| *K* | Inter-urban | 26.2 | 6 | | 6 | | 51 ft. | 43 ft. | | 4 | G. … |
| *L* | Inter-urban | 40 | 13 | | 13 | | 52 ft. | 42 ft. | | 2 | 150 … |

* W. H. (Westingh…

| Miles per Hour | Generators: Number of Generators | Generators: Output per Generator Kilowatts | Engines: Number of Engines | Engines: Indicated Horsepower per Engine | Engines: Type of Engine | Boilers: Number of Boilers | Boilers: Horsepower per Boiler (Boiler Rating) | Boilers: Type of Boiler | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | 2 | 400 | 2 | 500 | Horizontal cross-compound, direct-connected | 3 | 300 | Horizontal water-tube | Flat cars not equipped with motors. A. C. distribution from substations |
| | 2 | 800 | 2 | | Horizontal cross-compound, direct-connected | 6 | 500 | Horizontal water-tube | A. C. distribution to four substations each containing two 300-kilowatt rotary converters |
| 0 | 2<br>2 | 150<br>200 | 2<br>2 | 175<br>300 | Tandem compound, belted; tandem compound, direct-connected | 2<br>2 | 150<br>300 | Horizontal return tubular; horizontal water-tube | D. C. distribution used throughout |
| 8 | 6 | 700 | 6 | 750 | Tandem compound, vertical | 8 | 500 | Horizontal water-tube | Combined water-power and steam plant. Each generator driven either by engine or water wheels giving 1,200 horsepower under 25-foot head |
| | 2 | 250 | 2 | 400 | Horizontal compound, direct-connected | 3 | 260 | Horizontal water-tube | A. C distribution. Freight car has same motor equipment as passenger cars |
| | 1<br>1<br>2 | 200<br>225<br>800 | 1<br>1<br>2 | 300<br>300<br>1,200 | Vertical cross-compound, belted, horizontal cross-compound, direct-connected | 6 | 300 | Vertical water-tube | D. C. transmission. Boosters used on long feeders. Three storage-battery substations |
| | 2 | 350 | 2 | 500 | Direct-connected | 4 | 175 | Return tubular | D. C. transmission. Power house located near center of road |
| | 2 | 400 | 2 | 625 | Horizontal cross-compound, direct-connected | 4 | 310 | Horizontal water-tube | D. C transmission. Distant parts of line supplied through booster feeders |
| | 2 | 1,000 | 2 | | Horizontal cross-compound | 6 | 450 | Horizontal water-tube | D. C. transmission |
| 30 | 2<br>1 | 540<br>360 | 2<br>1 | 750<br>500 | Tandem compound, direct-connected | 4 | 300 | Vertical water-tube | A. C. transmission |
| | 3 | 400 | 3 | 600 | Cross-connected simple engines | 6 | 300 | Horizontal water-tube | Cars equipped with multiple-unit control. Each generator driven by a pair of 300-horsepower cross-connected simple engines |
| ne<br>I | 2 | 1,250 | 2 | 2,000 | Vertical cross-compound, direct-connected | 5 | 400 | Horizontal water-tube | Double-current generators are used (600-volt, direct current, 360-volt alternating current) |

starting resistance. The average power consumption per ton-mile will seldom be less than 90 watt-hours and in most cases will exceed this amount; 110 to 120 watt-hours may be taken as a fair approximation. The watt-hours per car mile will usually lie between 750 and 1,500 for single-truck cars with two motors of 30 or 35 horsepower, and between 1,500 and 2,500 for double-truck cars with four motors of 30 or 35 horsepower. Table III shows the results of tests on a number of different runs with motors of the sizes ordinarily used for operation in cities. The first two cars are equipped with a single motor with rheostatic control; all the others have series-parallel control.

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### EXAMPLES FOR PRACTICE

1. If 25 pounds per ton is required to propel a 30-ton car on a level track, what total force must be applied to propel the car up a 2-per-cent. grade? Ans. 1,950 lb.

2. If a total force of 500 pounds is required to propel a car at the rate of 15 miles per hour, how many horsepower are expended in moving the car? Ans. 20 H. P.

3. (*a*) If a car weighs 25 tons, what force must be applied to produce an acceleration of 1.25 miles per hour per second? (*b*) What must be the total force applied to produce the acceleration and overcome the train resistance as well, assuming that the latter amounts to 20 pounds per ton weight of car? Ans. $\begin{cases} (a) & 2,850 \text{ lb.} \\ (b) & 3,350 \text{ lb.} \end{cases}$

4. A certain car has 60 per cent. of its weight resting on the driving wheels and the adhesive force between track and rail is 15 per cent. of the weight on the drivers. A force of 75 pounds per ton weight of car is necessary to start the car from rest. What is the steepest grade on which the car can be started without slippage of the wheels on the tracks? Ans. 5.25 per cent.

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## EXAMPLES OF RAILWAY EQUIPMENT

**59.** In order to show the character of station equipment used for the operation of a number of typical railways, Table IV is here inserted. In all cases, except *K*, compound condensing engines are used; road *K* is situated in a coal-mining region where fuel is cheap and water suitable for

condensing purposes scarce; hence, simple non-condensing engines are used. On all the roads except *G*, water-tube boilers are used; this type of boiler is almost essential in railway work because the demand for power fluctuates greatly and the steaming of the boilers must respond quickly to the changes in load. Also, they must admit of forcing beyond their regular capacity in cases of emergency.

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## COST OF POWER

**60.** The cost of generating power in electric-railway plants varies greatly, as one would naturally expect, because it includes many items that are subject to wide fluctuation. In fact, in even the same station the cost will be higher during some months than others. Table V, from the Street Railway Review, gives figures relating to the cost of generating power in some stations of considerable size. It should be noted that the total cost covers only the items of fuel, labor, supplies, water, and repairs. It does not allow for interest on the investment, or depreciation of the plant. The cost per kilowatt-hour, not including interest and depreciation, will lie between .65 cent and 1 cent for many steam-power stations. In a large number of plants the total cost, including interest, etc., will lie between 1 and 2 cents per kilowatt-hour and in some of the largest plants it may be somewhat below 1 cent per kilowatt-hour. When power is sold from one railway company to another a common charge is 3 cents per kilowatt-hour. Every station switchboard should be equipped with at least one recording meter for measuring the station output, and it is a good plan to provide two meters so that one can operate while the other is being calibrated. In case only one instrument is used, it should be checked at frequent intervals to see that its indications are correct.

**61. Station Record.**—In order that the cost of generating power in a station may be accurately known, it is necessary to keep a complete record of the various elements

# TABLE V

## COST OF POWER FOR ELECTRIC RAILWAYS

*(Output Measured by Wattmeter in Each Case)*

| Station | Month | Monthly Output Kilowatt Hours | Cost of Electrical Output per Kilowatt Hour Cents | | | | | | Gallons of Cylinder Oil per 10,000 Kilowatt-Hours | Gallons of Lubricating Oil per 10,000 Kilowatt Hours | Pounds of Water per Pound of Coal | Pounds of Fuel per Kilowatt-Hour | Price of Fuel per Ton of 2,000 Pounds | Kind of Fuel |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Fuel | Labor | Supplies—Oil, Waste, Etc | Water | Repairs | Total | | | | | | |
| 1 | Jan | 2 455,000 | 322 | .111 | 029 | 029 | .044 | .535 | 2.62 | 848 | 10 83 | 2.45 | $2 63 | Bituminous |
| | Feb. | 2 511,230 | 334 | 114 | 036 | 027 | 025 | .536 | 2 64 | .829 | 10.05 | 2 54 | 2 63 | Bituminous |
| | Mar. | 2,077,100 | 337 | 123 | 037 | 030 | .040 | .567 | 2 84 | 987 | 11 21 | 2.55 | 2 64 | Bituminous |
| | Apr. | 2,158,000 | 344 | .129 | 039 | 032 | .043 | .587 | 2 98 | 722 | 11 37 | 2.61 | 2.64 | Bituminous |
| | Jan | 2 445,161 | 408 | 110 | 013 | 011 | 016 | 558 | 2 18 | 1.31 | 5 51 | 4 10 | 1 99 | Bituminous |
| | Feb | 2 512,125 | 389 | .116 | .014 | .008 | .011 | 538 | 2 50 | 1 08 | 5 32 | 3.89 | 2 00 | Bituminous |
| | Mar. | 2 352,098 | 405 | .126 | 018 | 011 | 016 | 576 | 2.52 | 1.70 | 5.15 | 4.33 | 1.87 | Bituminous |
| 5 | Apr. | 1,887,029 | 347 | 149 | 020 | .011 | .036 | .563 | 3.91 | 1.14 | 5.22 | 4 22 | 1 65 | Bituminous |
| 6 | Nov | 827,008 | 712 | .198 | .033 | | 067 | 1 010 | | | | 2 35 | .943* | Oil |
| 6 | Dec | 810,728 | 709 | 198 | 024 | | 070 | 1 001 | | | | 2.36 | 937* | Oil |
| 6 | Jan | 643 482 | 680 | 251 | 038 | | 185 | 1.154 | | | | 2 24 | .945* | Oil |
| 6 | Feb | 494,000 | 655 | 282 | 037 | | .181 | 1.155 | | | | 2.25 | .905* | Oil |
| 6 | Mar. | 562,574 | .761 | 266 | 031 | | .059 | 1.117 | | | | 2 42 | 976* | Oil |
| 6 | Apr | 610,634 | 628 | .236 | .030 | | .095 | .989 | | | | 2.31 | .843* | Oil |

* Price of oil per barrel

entering into the cost, together with the total output of the station. By dividing the total cost of operation per day by the total output in kilowatt-hours, as indicated by the recording instruments, the cost per kilowatt-hour is obtained. Fig. 27 shows a form of daily chart that gives all the necessary information in a very compact manner and indicates the actual readings as taken for a 24-hour run of the Camden and Suburban Railway Company's power station. This is a direct-current plant throughout. Distant parts of the system are supplied through boosters, and on the date represented by the chart two storage batteries were also in operation. The switchboard is equipped with high-potential and low-potential bus-bars. The full size of the chart is 23½ inches by 25 inches, and in the upper part are shown: first, the voltmeter readings on both high- and low-potential bus-bars; second, the storage-battery current; third, the readings of the main-station ammeter. All these readings are taken at 15-minute intervals and the heavy lines represent the average current from 7 A. M. until midnight, and from midnight to 7 A. M. The vertical dotted lines show the length of time and the hours during which each booster, generator, boiler, etc. was in use; feedwater temperatures, vacuum-gauge readings, etc. are also recorded as shown. In the lower left-hand part of the chart, the readings of the recording meters are given by marking the position of the hands on the printed dials. For the 24 hours, the total output as indicated by the two main recording instruments was 30,225,000 watt-hours, or 30,225 kilowatt-hours; the dial readings are indicated by the figures immediately above each dial, and they must be multiplied by the meter constant 5 and three ciphers added to the result to give the watt-hours, as shown at the bottom of the chart. The remainder of the chart is self-explanatory. The total cost of operation, including repairs, for the 24 hours is $200.17, making the cost per kilowatt-hour $.0066, or .66 cent.

# LINE AND TRACK

(PART 1)

## THE LINE

**1.** The term **line**, when used in connection with an electric railway, covers quite a large field of work. It may apply to the wires used for supplying current to the cars, or to a high-tension transmission line for transmitting the power from a distant power station. It also includes the various devices used for transmitting the current for cars operated by surface-contact or by conduit systems.

### OVERHEAD LINE WORK

**2. General Features.**—When **overhead construction** is spoken of, it is generally understood to refer to the common overhead-trolley system that is used wherever it is permitted, because it is so much cheaper than any of the other systems. Overhead construction includes the setting of the poles, the stringing of the feed-wires and the trolley wire, with its span wires, guard wires, anchor wires, insulating hangers, coupling devices, switches, etc. The feed-wires, or feeders, i. e., the wires communicating directly between the generators at the station and the several points of distribution, are carried overhead or are laid underground if necessary. When the feeders are carried overhead, it is the rule to support them on cross-arms from the same poles that support the span wires and trolley. Sometimes, however, if the feeder followed the line of the track, it would be unnecessarily long; in such a case, its route would lie across country or across town, as the case might be.

**3.** In Fig. 1, $P$ is the site of the power house, and $k$–$a$–$CB$–$b$–$e$ is the trolley wire, which of course has to follow the track. The wire is divided into two sections, $a$ and $b$, separated by the line circuit-breaker, or section insulator, $CB$; the term circuit-breaker used in connection with line work denotes a fitting for putting a break, or insulating joint, in the trolley line. Each section of the wire is fed by its own feeder. Feeder $b_1$ feeds into section $a$ at $a$ and follows the line of the track up to that point; $b_2$ feeds the second section at $b$, but instead of following the track and taking the long path around, as shown by the dotted line, it cuts across, as shown by the full line, thus effecting a great saving in length. It is, as a rule, cheaper in such cases to take the short cut, even if a pole line has to be erected just for the feeder, because great length in a feeder not only means a great outlay in copper, but the additional resistance helps to defeat the purpose of the feeder—that of keeping the voltage up to a practicable value on the line.

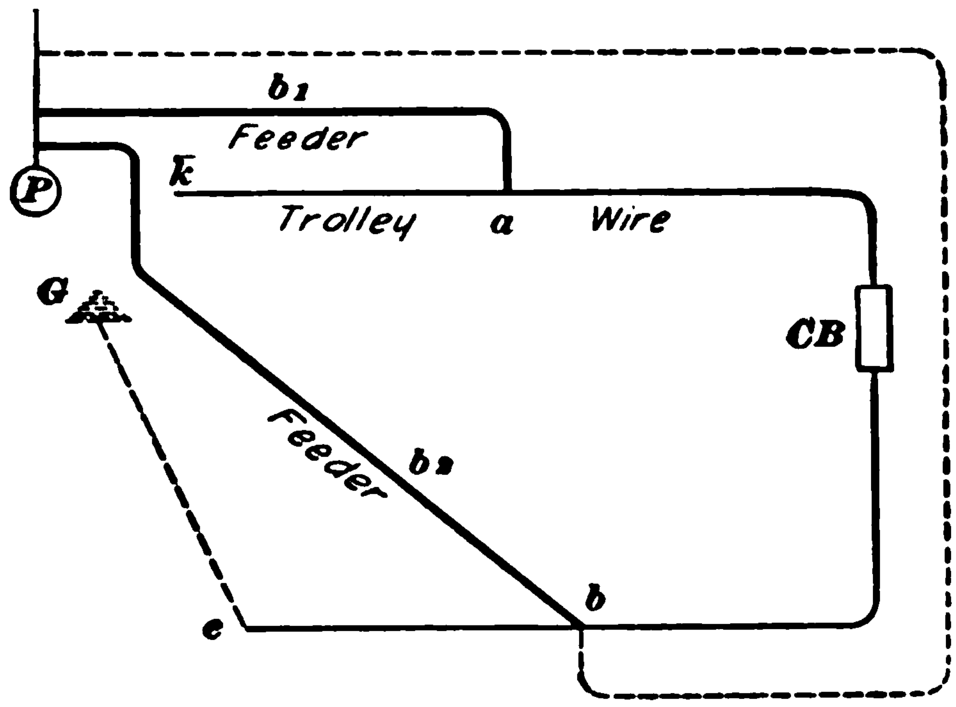

FIG. 1

**4.** Most overhead-trolley systems use a **rail return**, and it is just as important to provide a good path in the return circuit as in the outgoing lines; in fact, in some cases it is of more importance, because when the rail circuit is poor, current is liable to return on neighboring pipes and thus cause damage by electrolysis, as will be explained later.

Fig. 1 shows that although feeder $b_2$ allows the current a short path from the power house to the point of distribution $b$, it does not provide a short path back to the power house. The return current must follow the rail, and it would be very easy under such conditions for a greater drop to take place

in the track return than in the overhead feeder. A ground wire run from some point on the rail in the neighborhood of *b*, or even from the end *e* to the ground bus-bar at the power station, would greatly improve the service.

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## FEEDERS

**5.** The distributing system of an electric railway may be generally divided into two parts—the **feeders** and the **working conductor.** The latter usually takes the form of a trolley wire in overhead work, but it may be a third rail or the conductor rail in a conduit system. The feeders are usually in the form of heavy cables run from the station to supply different sections of the working conductor. In small towns and cities or on cross-country roads, feeders are run on poles, because this is the cheapest construction. In large cities, however, they are run underground. City ordinances often prohibit running them overhead on account of their unsightliness and also on account of their being a nuisance and source of danger in case of fires. Underground construction is expensive, but it has its advantages. Electric-railway companies objected very strongly when they were first required to put their feeders underground, but many of them are now strongly in favor of it. Underground wires are not disabled by snow and sleet storms, and on the whole their service is more reliable than that of overhead wires.

Where feeders are run underground, they are usually in the form of lead-covered cables; these are pulled into ducts, and manholes are provided at intervals to allow access to the cables for making repairs and locating faults, as previously explained in connection with the general subject of line construction.

**6. General Methods of Feeding.**—The simplest method of line construction is to use a single wire, serving both the purpose of trolley wire and feeder; but with a heavy load, the drop of potential at the end of the line, except in special cases, is too great when the trolley wire

alone is used. It is, therefore, necessary to run a heavy cable alongside the trolley wire and tap it into the wire at intervals along the route. Such a plan is shown in Fig. 2, where *m n* is the trolley wire, *a b* the feeder, and *f*, *f*

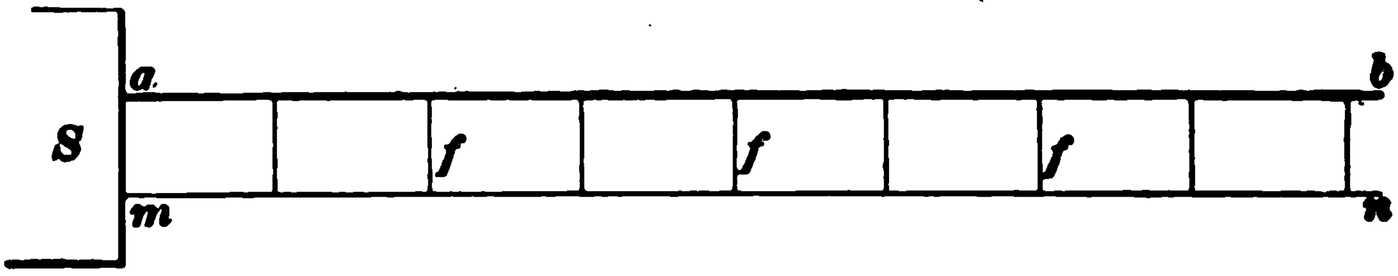


FIG. 2

the taps; the power station is supposed to be at one end of the line at *S*. It would be much more economical if the power station were in the center, as in Fig. 3, so that it might feed in both directions and thereby halve the distance from the power house to either end of the line.

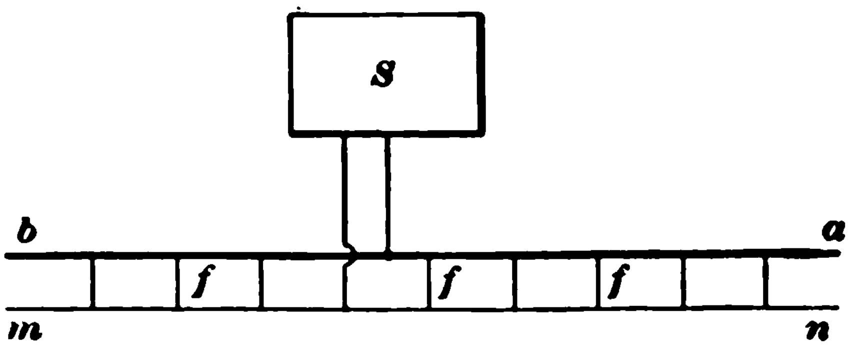


FIG. 3

If the trolley wire is divided into a number of sections *c*, *d*, *e*, *f*, *g*, each connected at its center to the feeder *a b*, as shown in Fig. 4, the drop in potential at any point would be due only to the feeder and that portion of the trolley line between the point in question and the tap. In case of a fire at any place along the route or in case of a ground on a bridge or in a tunnel, the power could be shut off in that district without disturbing the other parts of the

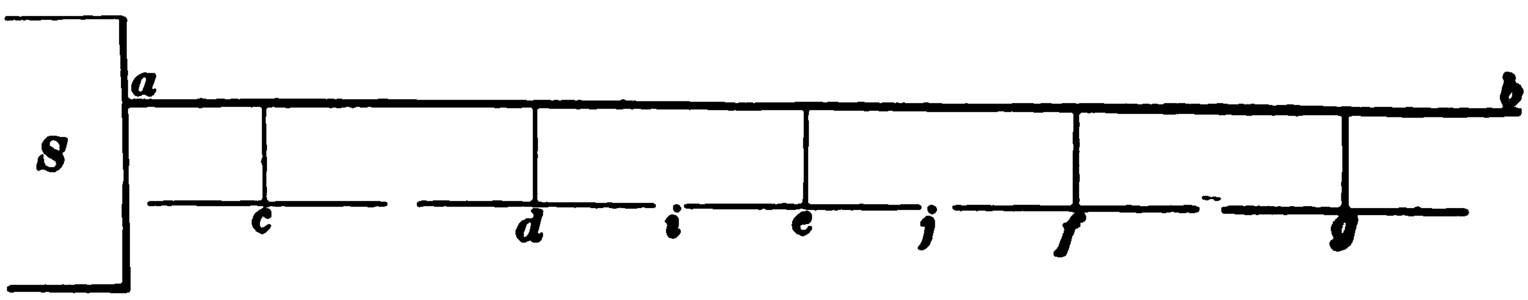


FIG. 4

line. To do this, each tap should be provided with a switch, Fig. 5, mounted on the pole at the point of connection to the feeder. The lower terminal is connected to the trolley, and when the switch is opened the blade can be thrown all

the way down and the door closed. All the exposed parts are then dead and the switch cannot be closed until the door is unlocked. The several sections of the trolley wire are well insulated from one another by line circuit-breakers, or section insulators, which will be described later.

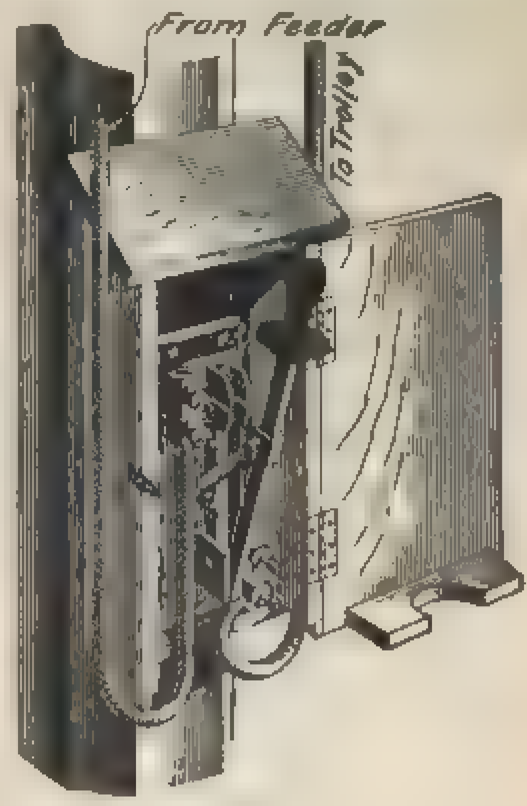


FIG. 5

**7.** Fig. 6 is a plan of feeder wiring that approaches the condition where the trolley wire is divided into several sections, each of which is provided with its own feeder. But in the case shown in Fig. 6, each feeder supplies several sections of trolley wire by means of extension feeders or mains *a f*, *f b* on the end of the main feeder and an independent tap running to each section of trolley. It is advisable to connect the ends *b i* of the mains by means of a fuse or circuit-breaker, thus tying the different parts of the system together. Then, in case one part is heavily loaded, the feeders and mains supplying the other part can help to supply current. For example, if section *i j* carries a heavy load, current can be supplied by way of feeder *e f* and main *f b*, but if a short circuit or excessive overload occurs on *i j*, the

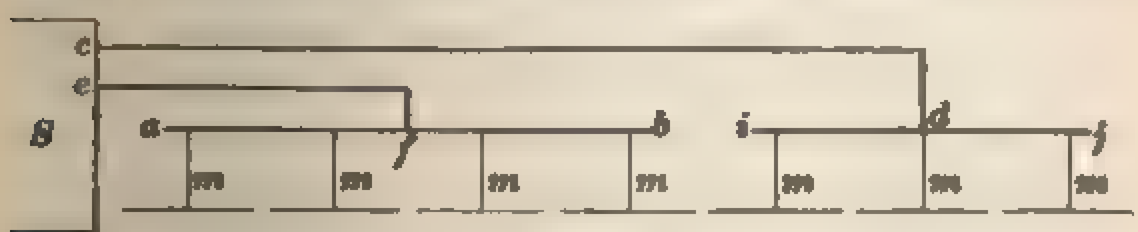


FIG. 6

fuse or circuit-breaker at *b i* will let go before the main circuit-breaker on feeder *e f* in the station, with the final result that current will be cut off from section *i j* but not from the rest of the road. Where several feeders are run out from a

station, it is advisable to tie them together in this manner, because it will help greatly to equalize the voltage, and if circuit-breakers are installed at the junction points and properly adjusted so that they will trip before the circuit-breakers in the station, the power, in case of short circuits or excessive overloads, will be cut off from only that section on which the trouble exists.

Fig. 7 shows the best plan for a feeder service. In this case, each trolley section has a feeder of its own. Of course,

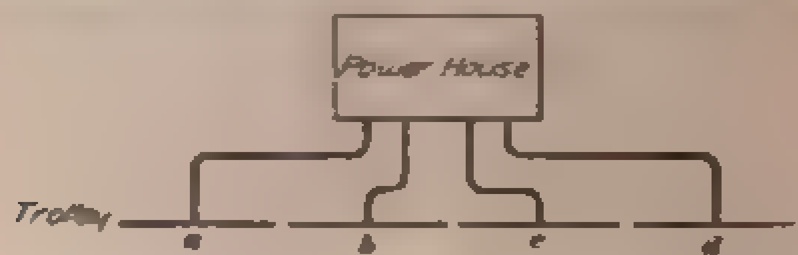


FIG. 7

the feeder is tapped into its section in as many places as may be deemed advisable. Each feeder and its section of trolley wire may be looked on as a single unit, and the idea can be extended to any system, however large. Such a plan not only simplifies calculations, but limits the field for troubles as well. Any trolley section can be cut out by means of its feeder switch.

**8. Booster Feeders.**—Fig. 8 shows the layout of feeders for an interurban road in Ohio, and illustrates the use of booster feeders for supplying distant sections. The road is 18½ miles long and the power house is situated 6 miles from one end. The two 6-mile sections on either side of the power house are fed directly from the generators, while the two distant sections at the left are fed through boosters. Thus, on section No. *3*, the feeder runs over 10 miles from the power house before it is tapped to the trolley wire, and the feeder for No. *2* section runs for over 6 miles before being tapped. Each section can, therefore, be supplied with different voltages at the power station, thus compensating for the larger drop and maintaining an approximately uniform voltage on all parts of the road. In Fig. 8, the two No. 00 trolley wires are tied together and attached to the feeder,

there being about four trolley-feeder taps to the mile. Current is carried from the rails to the station by four return feeders of 795,000 circular mils each. The trolley feeders are not of the same cross-section throughout, but are reduced in size after they begin to tap into the trolley wire. For example, the feeder for No. *3* section is 715,500 circular mils for 10¼ miles from the station and 397,500 circular mils for the remainder of the distance. The road for which this feeding system is designed operates on an average six interurban cars 49 feet 5 inches long over all, equipped with four 75-horsepower motors geared for a maximum speed of 40 miles per hour. The feeders are of aluminum and their cross-section for equal conductivity, if made of copper, would be about 60 per cent. of the cross-sectional areas indicated in Fig. 8.

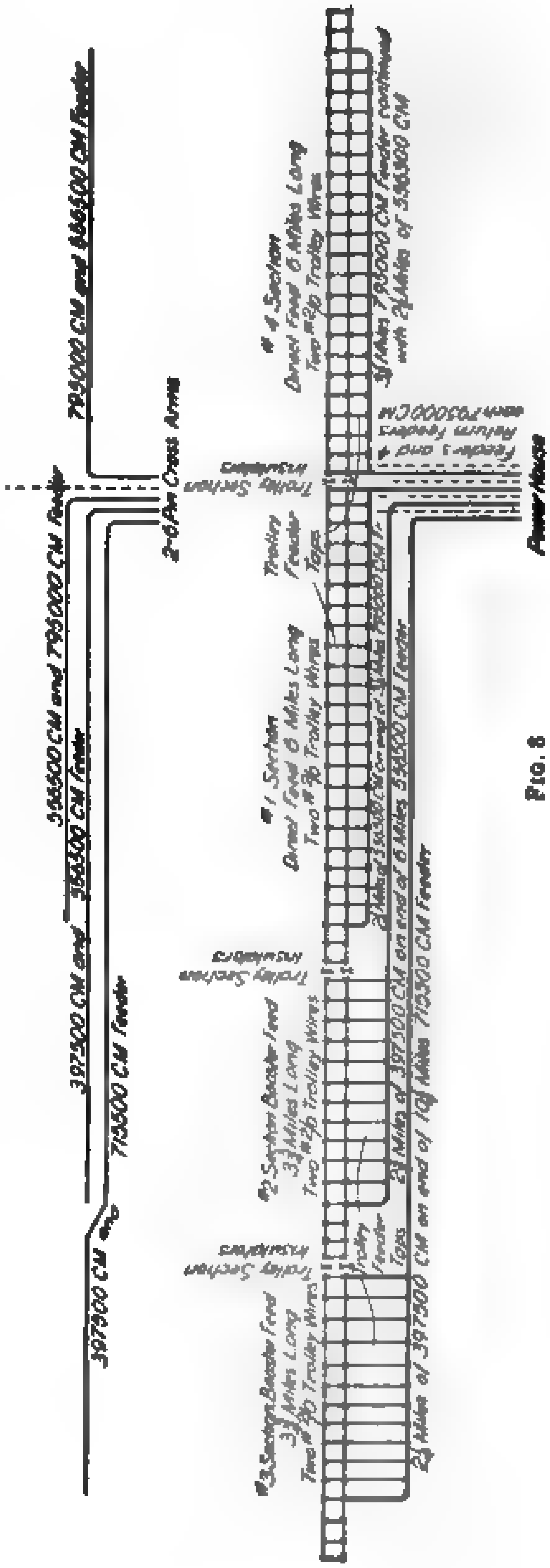


FIG. 8

In selecting the points

to which booster feeders are run, it is frequently advisable to bear in mind the possibility of installing line storage batteries at some future date, and choose locations where sites for storage-battery substations can be obtained without difficulty.

9. **Overhead feeders** are usually in the form of heavy stranded cables covered with weather-proof braided insulation. If a very large feeder is not required, solid wire may be used or two or more wires may be run in parallel to make up the requisite cross-section. Table I gives the make-up of triple-braided weather-proof railway feeder cables as manufactured by the American Electrical Works.

TABLE I

WEATHER-PROOF FEEDER CABLES

| Size Circular Mils | Style of Conductor | Approximate Weight per Mile Pounds |
|---|---|---|
| 1,000,000 | 61 wires, .128 each | 19,000 |
| 950,000 | 61 wires, .125 each | 18,250 |
| 900,000 | 61 wires, .122 each | 17,280 |
| 850,000 | 61 wires, .118 each | 16,320 |
| 800,000 | 61 wires, .115 each | 15,360 |
| 750,000 | 61 wires, .111 each | 14,400 |
| 700,000 | 61 wires, .107 each | 13,450 |
| 650,000 | 61 wires, .103 each | 12,480 |
| 600,000 | 61 wires, .099 each | 11,600 |
| 550,000 | 61 wires, .091 each | 10,560 |
| 500,000 | 49 wires, .101 each | 9,800 |
| 450,000 | 49 wires, .096 each | 8,600 |
| 400,000 | 49 wires, .090 each | 7,500 |
| 350,000 | 49 wires, .085 each | 6,500 |
| 300,000 | 49 wires, .078 each | 5,500 |
| 250,000 | 49 wires, .071 each | 4,860 |

Aluminum has been used, in some cases, for railway feeders, but unless the relative prices of copper and aluminum are such that the use of the latter effects a considerable

saving in cost, copper is preferred and is used in the great majority of cases. Since the conductivity of aluminum is about 60 per cent. that of copper, the cross-section of a copper feeder for a given service will be $\frac{6}{10}$ times that of an aluminum feeder for the same service, or the aluminum feeder will have a cross-section of $1\frac{2}{3}$ times that of a copper feeder. For example, if a 300,000-circular-mil copper cable is required for a given service, an aluminum cable for the same service must have a cross-section of $300,000 \times 1\frac{2}{3} = 500,000$ circular mils.

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### TROLLEY WIRE

**10. Material.—Trolley wire** is of hard-drawn copper for all ordinary work. In some cases, especially tough composition wire is used on curves where the wear is excessive. Trolley wire is seldom less than No. 0 B. & S., though on some old lines wire as small as Nos. 1, 2, or even 3 B. & S. was used. Some roads now use No. 000 or 0000, but No. 00 is by far the most popular size, and if the feeding system is laid out properly there is little advantage in using larger trolley wire. It only makes a greater weight to be supported by the span wires and hangers, thus increasing the cost of the line supports.

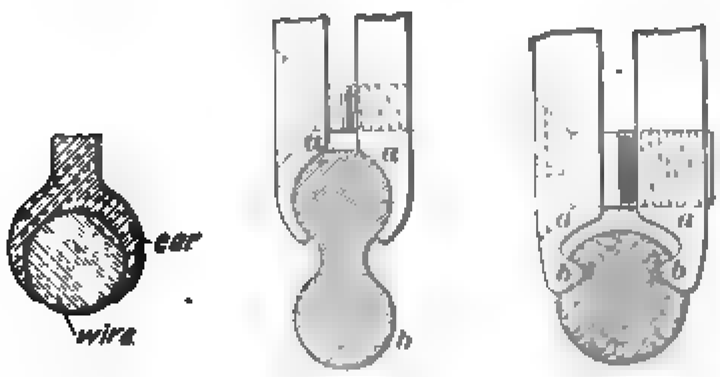
Hard-drawn copper is used because its tensile strength is greater and its wearing qualities better than soft copper. Its resistance is slightly higher, but this is of little consequence because the trolley is not usually depended on to carry the current for any great distance. Table II gives data on hard-drawn copper.

For trolley wire on curves or other places where there are strain and wear on the wire much greater than on straight stretches of track, **phono-electric** wire is frequently used. This is a special composition or alloy wire made by the Bridgeport Brass Company, and stated to have a tensile strength from 40 to 45 per cent. greater than that of hard-drawn copper; its conductivity is 50 per cent. that of pure copper.

## TABLE II
### HARD-DRAWN COPPER TROLLEY WIRE

| Number B. & S. | Diameter Mils | Area Circular Mils | Weight per 1,000 Feet Pounds | Weight per Mile Pounds | Resistance Ohms per 1,000 Feet | Resistance Ohms per Mile | Breaking Weight Pounds |
|---|---|---|---|---|---|---|---|
| 0000 | 460 | 211,600 | 640.5 | 3,381.4 | .05004 | .2642 | 8,310 |
| 000 | 410 | 167,805 | 508.0 | 2,682.2 | .06309 | .3331 | 6,580 |
| 00 | 365 | 133,079 | 402.8 | 2,126.8 | .07956 | .4201 | 5,226 |
| 0 | 325 | 105,535 | 319.5 | 1,686.9 | .1003 | .5297 | 4,558 |
| 1 | 289 | 83,694 | 253.3 | 1,337.2 | .1265 | .6679 | 3,746 |
| 2 | 258 | 66,373 | 200.9 | 1,060.6 | .1595 | .8423 | 3,127 |
| 3 | 229 | 52,634 | 159.3 | 841.09 | .2011 | 1.0620 | 2,480 |

**11. Shape of Trolley Wire.**—Trolley wire is nearly always round in cross-section, as this shape answers for most work in towns and cities where the speed is not high. Fig. 9 (*a*) shows the ordinary round wire held by a soldered ear. The ear is tapered down to an edge, so that it will allow the under-running trolley wheel to pass as smoothly as possible. Even if the fins on the ear are thin, there is always more or less of a jump when the wheel passes under the hanger, which causes trouble if the car runs at high speed; the sparking caused by the jump eats away the hanger and leads to breakage in course of time. The jump is even more pronounced if ears that clamp the wire, instead of being soldered, are used.




(*a*) (*b*) (*c*)

Fig. 9

For cross-country or interurban roads, where high speed is attained, it is very desirable to have the trolley wire so suspended that it will offer a smooth running surface for the

trolley. Fig. 9 (*b*) shows a wire designed to accomplish this. It is the shape of a figure 8 in cross-section and the upper part is gripped by the clamp ears *a*, *a*, the lower part *b* being free from obstruction. The objection to this style of wire is that if it becomes twisted between supports, so that it lies crosswise, the wheel does not run well.

Fig. 9 (*c*) shows a style of wire introduced by the General Electric Company. This wire, also, is supported by clamp ears *a*, *a*, and the surface presented to the trolley wheel is

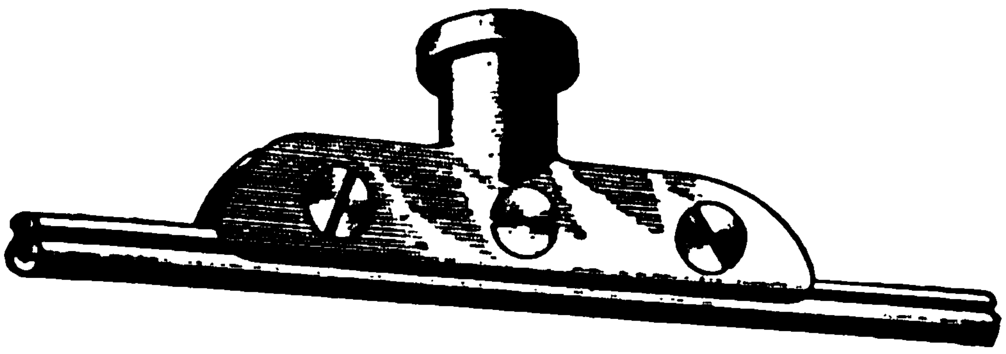


FIG. 10

smooth. The wire is practically circular in cross-section, with the exception of the two grooves *b*, *b* in the side, so that if the wire twists between supports it does not interfere perceptibly with the smooth running of the wheel when high speeds are attained. Fig. 10 shows the method of supporting this wire.

When soldered ears are used, the obstruction offered is so slight that a round wire answers in the great majority of cases. When clamped ears, however, are desired, and when high speeds are developed, these specially shaped trolley wires will be found advantageous.

### METHODS OF ARRANGING TROLLEY WIRE

**12.** There are three styles of support for trolley wires: they may be suspended from brackets on poles at the side of the road; a double track may be provided with center poles carrying the wires on a projecting arm on either side; or the poles may be placed at the sides of the street and the trolley wire supported by span wires stretched across.

**13. Span-Wire Construction.**—This is the most common method of suspension, and it is preferred for the

following reasons: In the first place, it does not obstruct the center of the roadway like the center-pole construction; in the second place, there are locations where only one side of the road can be used, as on country roads, where passages for two teams must be left outside of the track. Again, where a single track is laid with the prospect of making it a double track if the traffic warrants doing so, the side-pole span-wire construction leaves very little additional work to be done when the time comes for doubling the track. In such a case, it is sometimes the practice to string two trolley wires alongside of each other about 8 or 10 inches apart. As long as the road is single track, the cars use one wire when going one way and the other wire when returning; this saves overhead special work at turnouts and saves copper in the feed-wires. When the time comes for doubling the track,

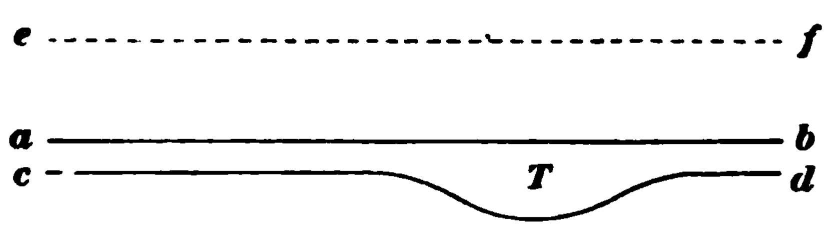


FIG. 11

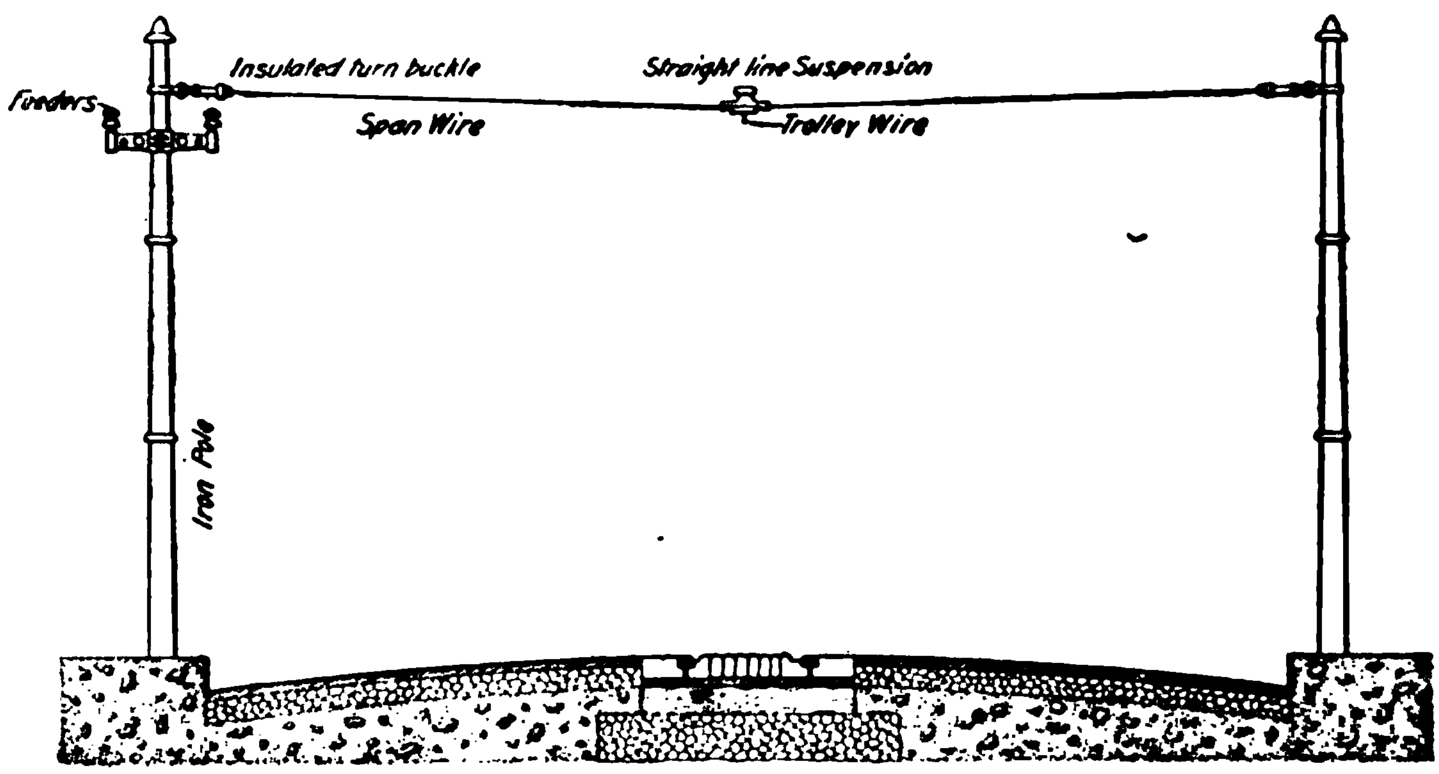


FIG. 12

it is only necessary to slide one wire into place and see to its insulation from the ground. In such straightaway construction, it may be that no feeders are used, in which case the road cannot be divided into sections, but the two wires must be continuous from the power house to the end of the line.

In Fig. 11, *a b* is one trolley wire and *c d* is the other; *T* is a turnout—a switch where cars can pass each other; the

dotted line *e f* shows the position of the wire *a b* after it has been moved over to the second track. This parallel construction does away with the necessity of any overhead

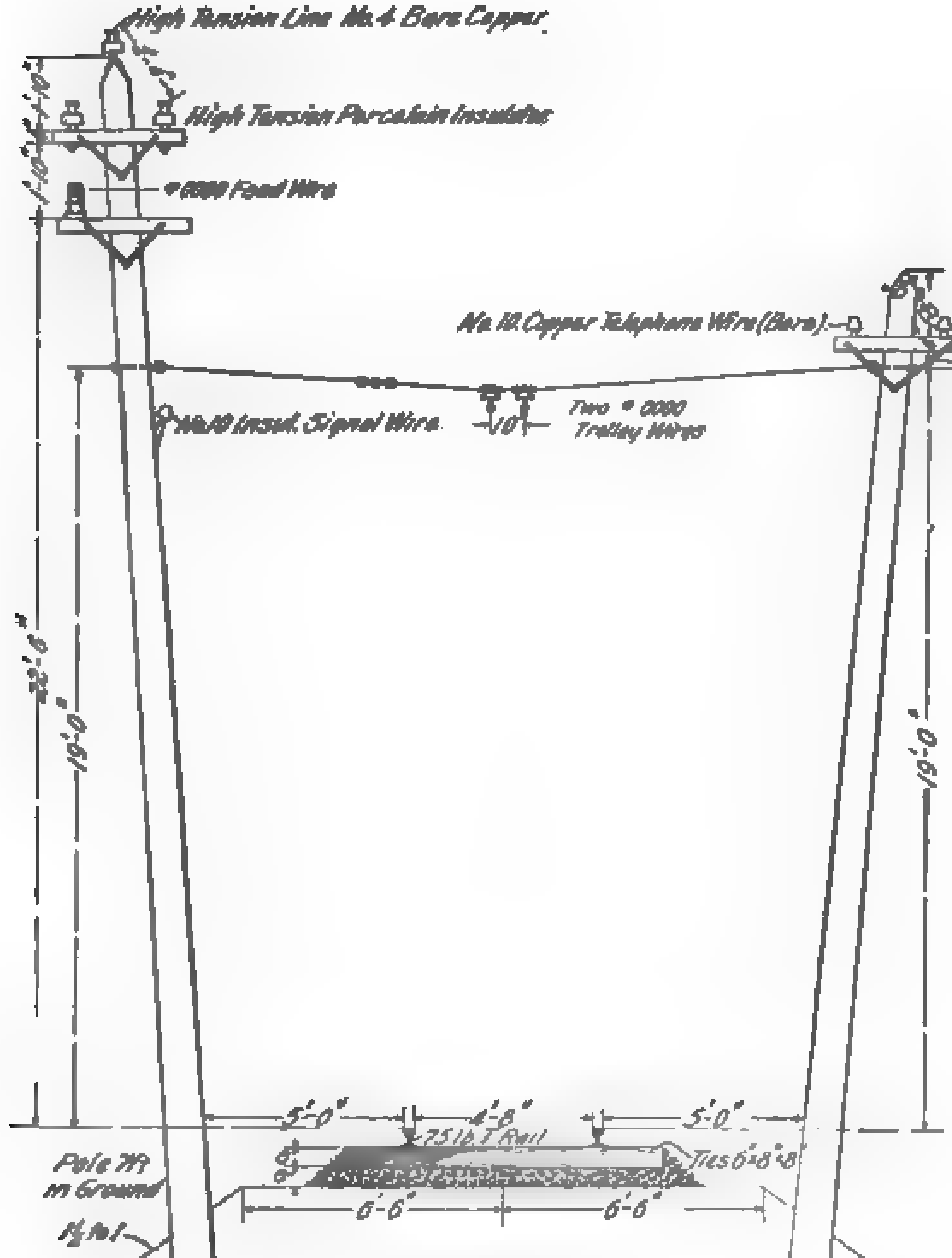



FIG. 13

special work at the turnouts, and if all turnouts are placed on the same side of the track, it leaves one wire straight.

**14.** Fig. 12 shows a general arrangement for span-wire suspension in cities. In this case iron poles are shown, so

that an insulating turnbuckle is used between the pole and the span wire. The trolley hanger is also insulated, so that there is high insulation between the trolley wire and the ground even though iron poles are used. The feeders are carried on cross-arms bolted to the poles. Where wooden poles are used, the insulated turnbuckles are often omitted. An eyebolt is simply passed through the pole and the span wire is stretched by screwing up a nut.

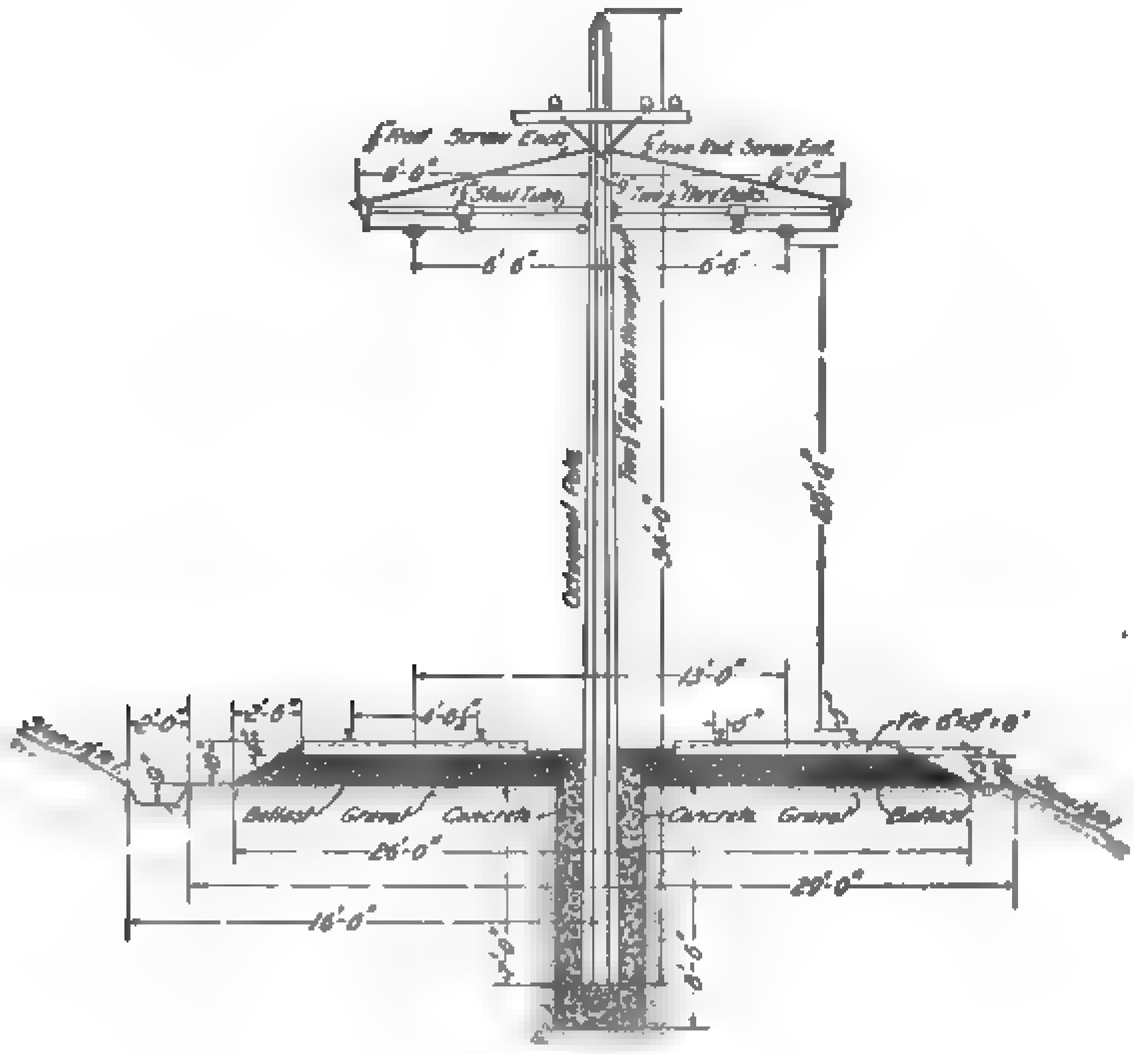


FIG. 14

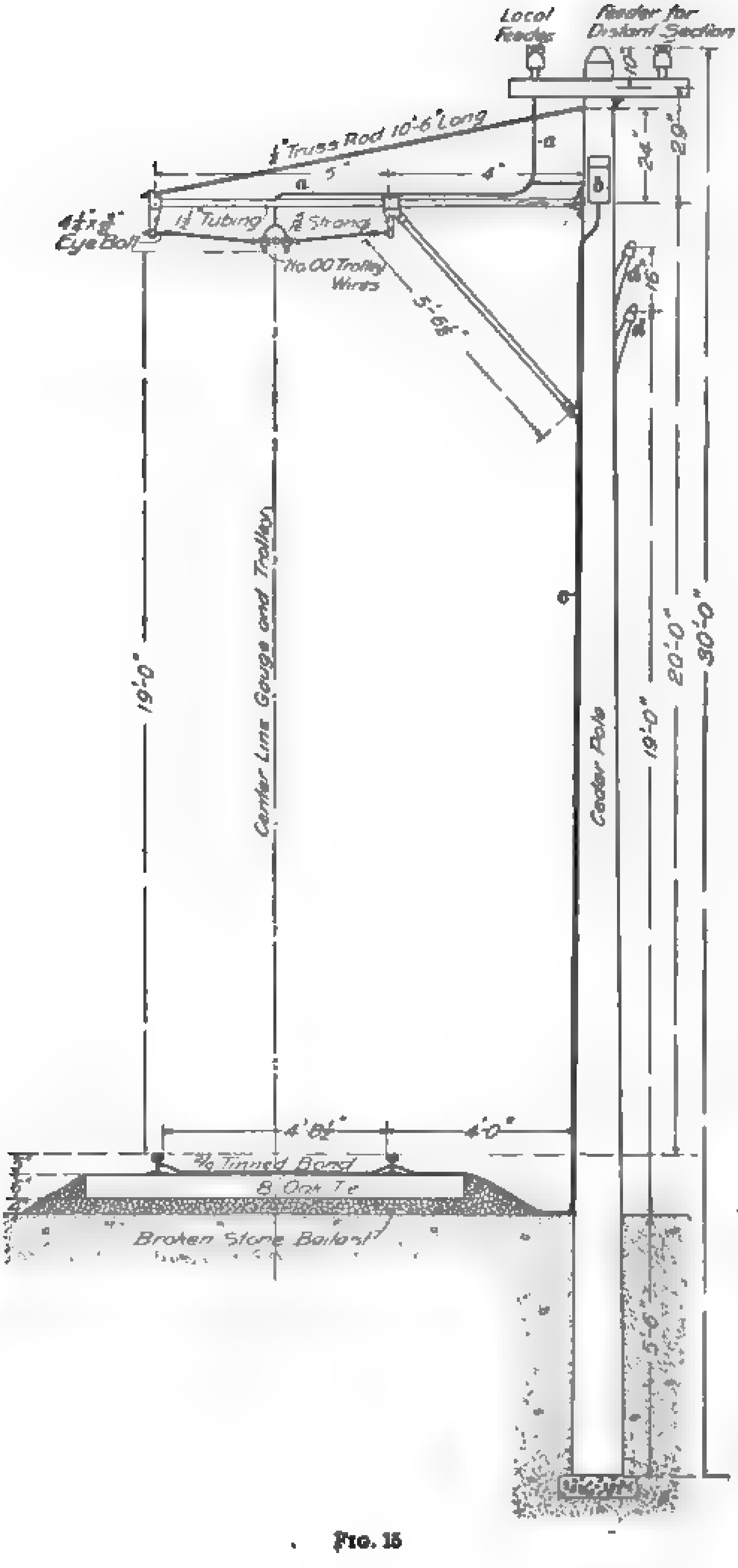
Fig. 13 shows a span-wire construction for a single-track interurban road where the poles carry a 16,000 volt three-phase transmission line in addition to the direct-current feed-wire. The suspension carries two No. 0000 trolley wires suspended 10 inches apart. The poles are 8 inches in diameter at the top and are set 7 feet in the ground. The span wire is of ⅜-inch twisted steel.

**15. Center-pole construction** can be used to good advantage on wide streets where poles in the center of the street will not obstruct the traffic. It is also much used for interurban roads operated with an overhead trolley.

Fig. 14 shows a substantial center-pole construction on an interurban road in New York State. The poles are of yellow pine, octagonal in cross-section, and are set in concrete, as shown, in order to give them a firm base. A single No. 000 trolley wire is used over each track and is suspended 20 feet above the rails. The trolley-wire hangers are attached to a small stranded steel cable, thus making the suspension flexible and taking up the blow of the trolley wheel as it passes the supports. The cross-arm carries a 500,000-circular-mil feeder and two No. 10 B. & S. copper telephone wires.

**16. Side-Bracket Construction.**—When this construction is used, the track is generally on one side of the street; it is used most extensively for cross-country lines where a single track runs along one side of the highway. For this class of work, cheap gas-pipe brackets are generally used; and since the construction calls for only one pole, whereas a span wire requires two, it is less expensive.

Fig. 15 shows a side-bracket construction of good design. The bracket is braced from above and below, a $\frac{1}{2}$-inch tie-rod being used for the upper brace and $1\frac{1}{4}$-inch pipe for the lower. The feeders are carried on the cross-arm and tapped on to the trolley wire, as shown by the connection *a*, *a*. Line lightning arresters are mounted at suitable intervals, five or more to the mile, as shown at *b*, and are connected to ground by No. 00 weather-proof wire *c*. The best way to obtain a ground for these arresters is to attach the ground wire to the rails, as indicated. Two trolley wires of figure 8 cross-section equivalent to No. 00 B. & S. are used; telephone wires are carried on side brackets *d*, *d*.



Local Feeder
Feeder for Distant Section
Truss Rod 10'-6" Long
5'
4'
24"
29"
Eye Bolt
Tubing
Strong
No. 00 Trolley Wires
5'-6"
16"
19'-0"
Center Line Gauge and Trolley
Cedar Pole
19'-0"
20'-0"
30'-0"
4'-8½"
4'-0"
Tinned Bond
8' Oak Tie
Broken Stone Ballast
5'-6"


FIG. 15

### POLES

**17.** Poles are either of steel or wood. For cross-country or suburban roads wooden poles are generally used, since appearances are not of so much consequence as with city roads; and even in cities, wooden poles are erected when there is no strong objection to them on the ground of unsightliness. For city work tubular wrought-iron or steel poles of the telescope type are very common; these are usually made up of three sizes of pipe welded together. Seamless steel-tube poles are also coming into much favor. Iron or steel poles are invariably set in concrete, for which the following is a suitable composition:

| | |
|---|---|
| Portland cement . . . . . . . . . . . . . | 1 part |
| Clean sharp sand . . . . . . . . . . . . . | 2 parts |
| Clean broken stone . . . . . . . . . . . | 3 parts |

**18. Wooden poles** are usually of chestnut, hard pine, cedar, or redwood. The use of redwood poles is confined mostly to a few of the western states. Poles with tops less than 8 inches in diameter should not be used in railway work; they may be suitable for some classes of telephone and telegraph line construction, but they are too light for the heavier work of electric railways. Chestnut poles should, preferably, be second growth and left in their round natural condition. Poles sawed to octagonal shape are usually of hard pine. In general, while sawed poles present a better appearance than round poles in their natural condition, the removal of the outer part of the wood shortens their life. If poles are kept well painted, their life will be prolonged, to say nothing of the improvement in their appearance. The part in the ground should, with the exception of the base, be coated with tar or some other preservative compound. Experience has shown that it is better to leave the bottom uncovered by the tar, because the center of the pole then remains constantly damp and does not rot as quickly. In many cases, poles are treated with creosote in order to prolong their life. Table III gives data relating to untreated poles of best quality American yellow pine or cedar.

TABLE III

APPROXIMATE SIZES, WEIGHTS, ETC. OF WOODEN POLES

| Length Feet | Diameter Top Inches | Diameter Bottom Inches | Volume Cubic Feet | Shape of Section | Weight Pounds | Allowable Side Strain for 7-Inch Deflection |
|---|---|---|---|---|---|---|
| 28 | 8 | 10 | 12.5 | Circular | 600 to 700 | 725 |
| 28 | 8 | 10 | 13.2 | Octagonal | 650 to 800 | 725 |
| 30 | 8 | 10 | 13.4 | Circular | 670 to 820 | 700 |
| 30 | 8 | 10 | 14.2 | Octagonal | 700 to 840 | 700 |
| 30 | 9 | 12 | 19.1 | Octagonal | 900 to 1,140 | 850 |

**19. Setting Wooden Poles.**—Wooden poles are not, as a rule, set with concrete, although there is no good reason why they should not be. When the side-pole span-wire construction is used, they should have their earth bearing increased by the proper disposal of several large stones. A couple of stones should be jammed into the hole alongside of the pole on the side away from the track and a couple more near the mouth of the hole on the side next the track. This will do a great deal toward preventing the span of wire from pulling the tops of the poles together. A piece of timber may be substituted for the stones on the track side, in which case it should be about 3 feet long and 8 square inches in cross-section. After the pole has been placed in position, it should be solidly tamped around to make a firm bed. The tamping should be done while the pole is free; if done while there is tension on the span wire, the effect will be just the opposite to that desired. On straight stretches of track, using side-bracket construction, the poles should be given a rake backwards from the track, the top of the pole not being more than 2 or 3 inches out of plumb. Where side poles are used, with span wires, the rake should be considerably greater because of the tendency of the span wire to pull the tops together (see Fig. 13). In soft ground, the rake should be from 8 to 12 inches, depending on the character of the ground and the kind of pole foundation; the more yielding

the soil the greater should be the rake. In setting poles having a rake, it is advisable to use a spirit level or plumb-bob; by doing this they will all be on a uniform slant, whereas if the eye alone is depended on, the pole line may be very uneven. The poles are usually spaced from 100 to 125 feet apart. In cities 100 feet, or about 53 to the mile, is a common average; while in other places, where a lighter construction is sufficient, they may be placed 125 feet apart, or about 42 to the mile.

**20. Tubular Steel Poles.**—Fig. 16 shows a tubular steel pole adapted to the various types of construction, (*a*) being for the side bracket, (*b*) for the center pole, (*c*) for the span wire. The method of attaching the span wire to the pole in (*c*) is shown in the small detail sketch. A

TABLE IV

APPROXIMATE WEIGHTS OF IRON POLES

| Style of Pipe | Diameter of Sections | | | Length Feet | Weight Pounds |
|---|---|---|---|---|---|
| | Bottom Inches | Middle Inches | Top Inches | | |
| Standard . . . . | 5 | 4 | 3 | 27 | 350 |
| Extra heavy . . . | 5 | 4 | 3 | 27 | 500 |
| Standard . . . . | 6 | 5 | 4 | 28 | 475 |
| Extra heavy . . . | 6 | 5 | 4 | 28 | 700 |
| Standard . . . . | 7 | 6 | 5 | 30 | 600 |
| Extra heavy . . . | 7 | 6 | 5 | 30 | 1,000 |
| Standard . . . . | 8 | 7 | 6 | 30 | 825 |
| Extra heavy . . . | 8 | 7 | 6 | 30 | 1,300 |

clamp is fastened around the pole and to it is attached a turnbuckle that allows the tension on the span wire to be adjusted. Usually this turnbuckle is insulated in order to provide insulation between the trolley wire and ground in addition to that afforded by the trolley-wire hanger. Feed-wires are carried on an iron cross-arm bolted to the pole,

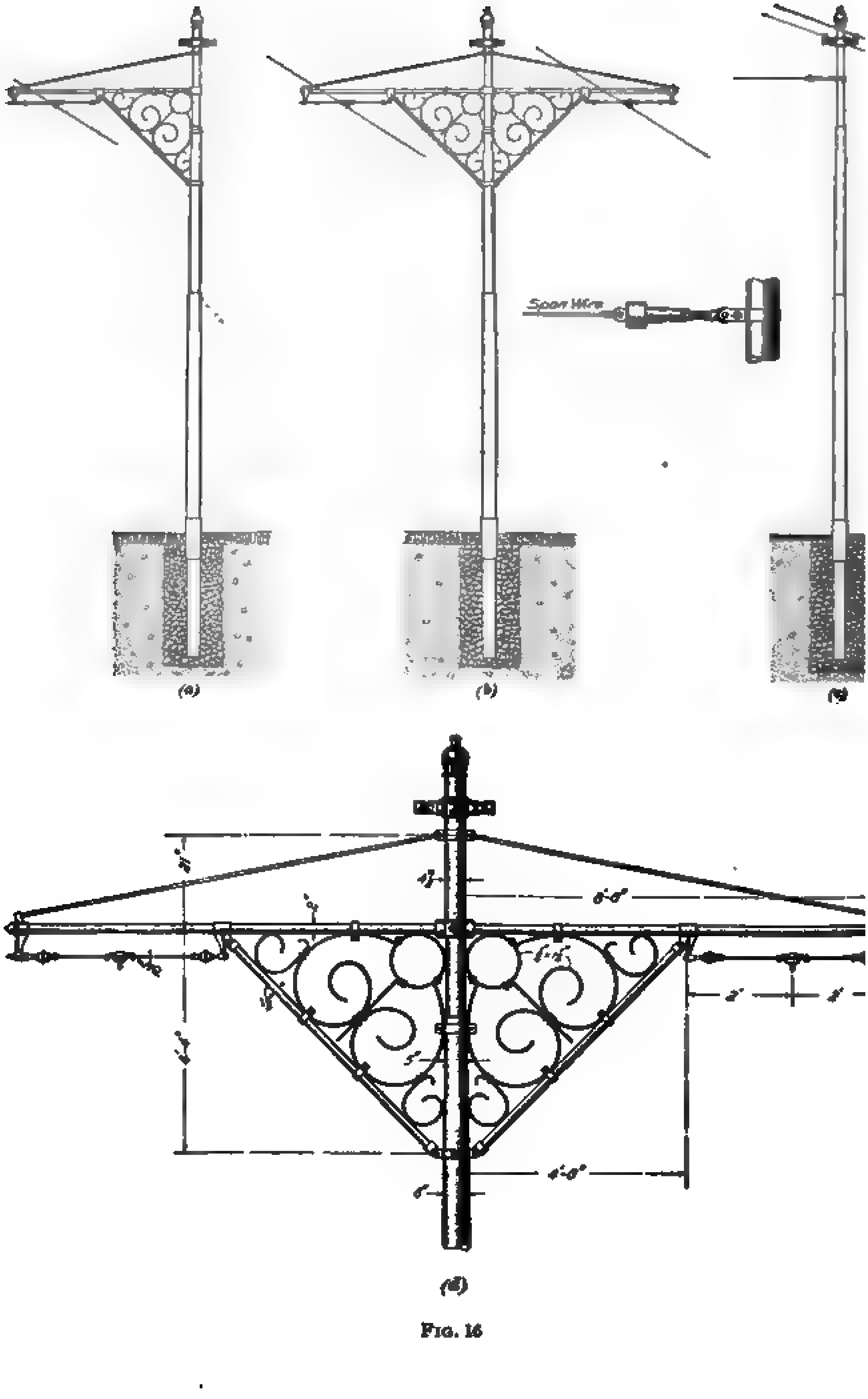



FIG. 16

as in (*c*). An enlarged view of the center-pole top is shown in (*d*). The trolley-wire hanger is not fastened rigidly to the horizontal cross-arm but is flexibly supported from a short span wire stretched between brackets; the span wire is usually made of stranded steel cable about $\frac{5}{16}$ inch in diameter. Table IV gives the approximate weight of iron poles.

Steel poles are sometimes made in other than the telescope tubular form. Poles made of pressed steel parts riveted together have been used; also latticework poles built up of structural steel. In the majority of cases, however, the telescope type of pole is the one generally adopted.

## LINE FITTINGS AND LINE ERECTION

### TROLLEY WIRE AND FEEDERS

**21.** The general arrangement of wiring for a double track is shown in Fig. 17. The poles *p* are placed not more than 125 feet apart measured along the road, and between opposite poles are stretched the span wires *s*. At intervals of about 500 feet and at the approach to all curves, anchor wires *a* are put up, being secured by special hangers, as at *h*. These take up the strain on the trolley wire in the

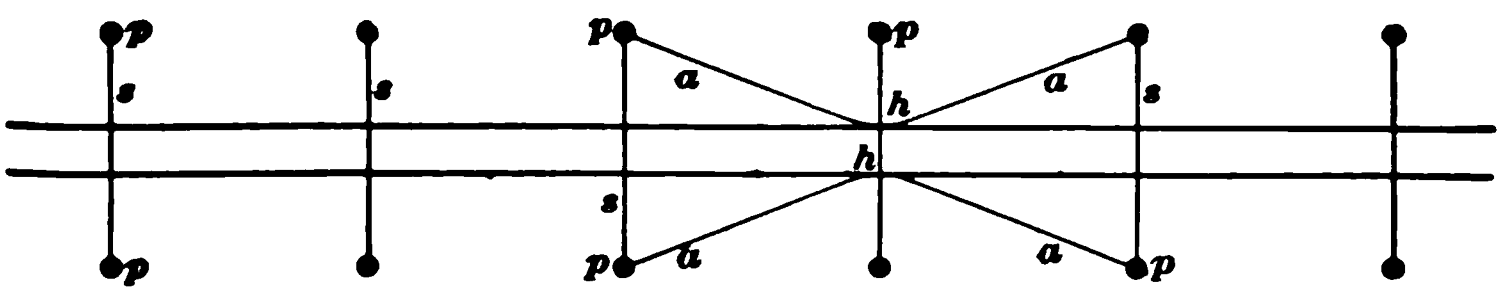



FIG. 17

direction of its length, for it must be borne in mind that the trolley wire is put up under considerable tension, so that should it break it would draw apart in both directions if there were no anchor wires to hold it in position. The two general methods of stringing the trolley wire depend on whether it is put up dead or alive; i. e., whether the current is off or on. In the first case, the wire is run off the reel

under the span wires and is then raised and tied temporarily to them; the tension is put on afterwards and the wire fastened to the insulators.

If the wire is put up alive, the reel is put on a flat car that is moved by a trolley car. As fast as the wire is paid off, it is fastened to the insulators, once for all, by a line crew that follows close behind. It may be necessary to go over the

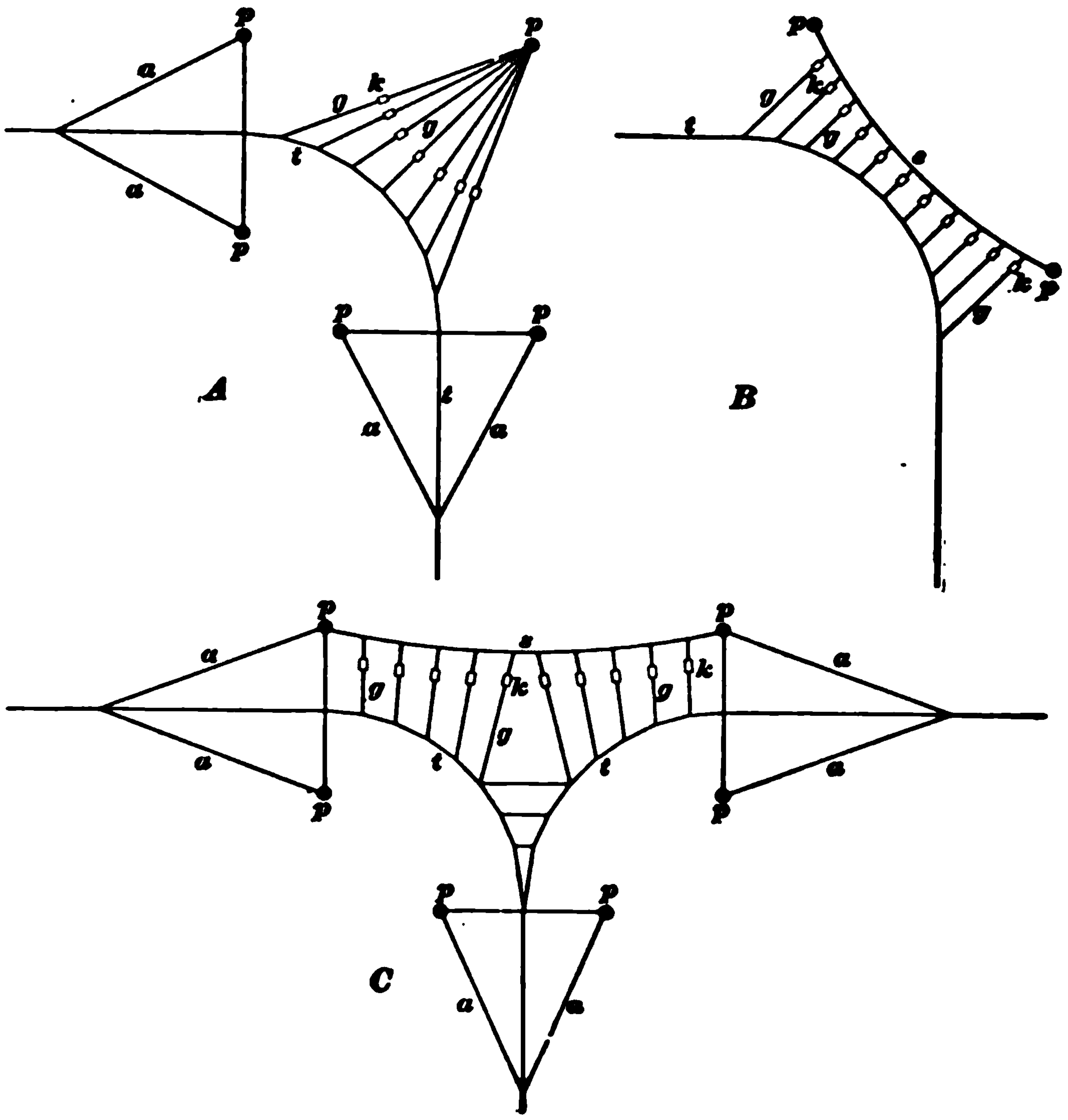



FIG. 18

road afterwards and make a final adjustment, especially at curves and crossings.

**22. Erection at Curves.**—The method of securing the trolley wire at curves is shown in Fig. 18, where *A* represents the arrangement of guy wires *g* attached to the trolley wire *t* when a single pole is used. Strain insulators are

usually inserted, as shown at *k*, and the trolley wire, at the beginning of the tangent or straight portion, is held by anchor wires *a*. A flexible method of suspension is shown in diagram *B*, where a heavy span wire *s* holds up the guy wires; this form of construction tends to equalize the strains on the span wires, and is generally adopted in place of *A*, which is the older method. A double curve is shown at *C*, the different wires and poles being designated by the same letters as in the preceding layouts.

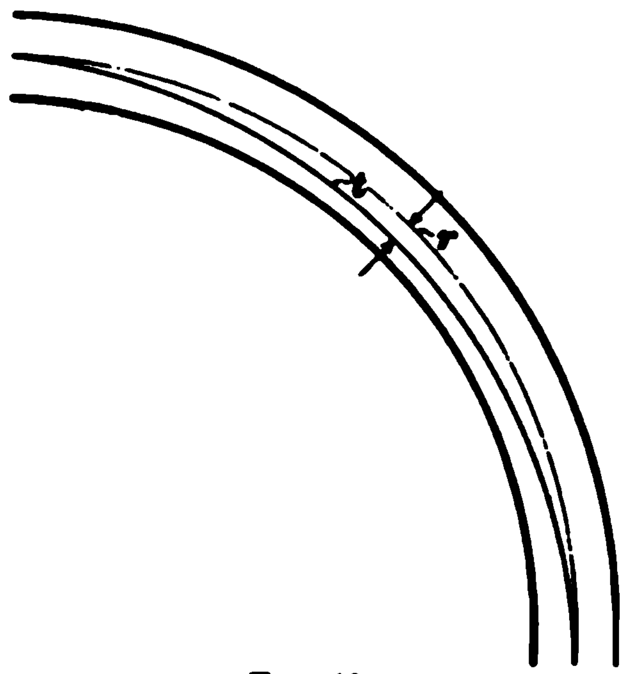


FIG. 19

**23. Offset in Trolley Wire.** In going around a curve, the trolley wire does not follow the center line between the rails as it would do if the trolley wheel were applied to the wire at a point immediately over the center of the car, but it is shifted over toward the inside rail by a distance that depends on the radius of the curve. This departure from the center line of the track is shown in Fig. 19, where the curve *r* is the center line of the rails and *t* the path of the trolley wire. The amount of offset measured at the middle of a 90° curve at the point indicated by the arrows in the figure should be about as follows:

| Radius of Curve | Offset |
|---|---|
| 40 feet | 16 inches |
| 50 feet | 13 inches |
| 60 feet | 12 inches |
| 80 feet | 8 inches |
| 100 feet | 6 inches |
| 120 feet | 5 inches |
| 150 feet | 4 inches |
| 200 feet | 3 inches |

The object of the offset is to allow the trolley wheel to lie more closely to the wire; it would not do this so well if the wire followed the center line of the track, as the wheel

would lie diagonally across the wire and cause a large amount of wear on curves.

**24. Guard Wires.**—In some places, guard wires are located above the trolley wires, as shown in Fig. 20. They are placed about 18 inches above and to one side of the trolley wire, their object being to prevent telephone or other wires from falling across the trolley wire. Guard wires are now very little used, as they are of doubtful advantage and

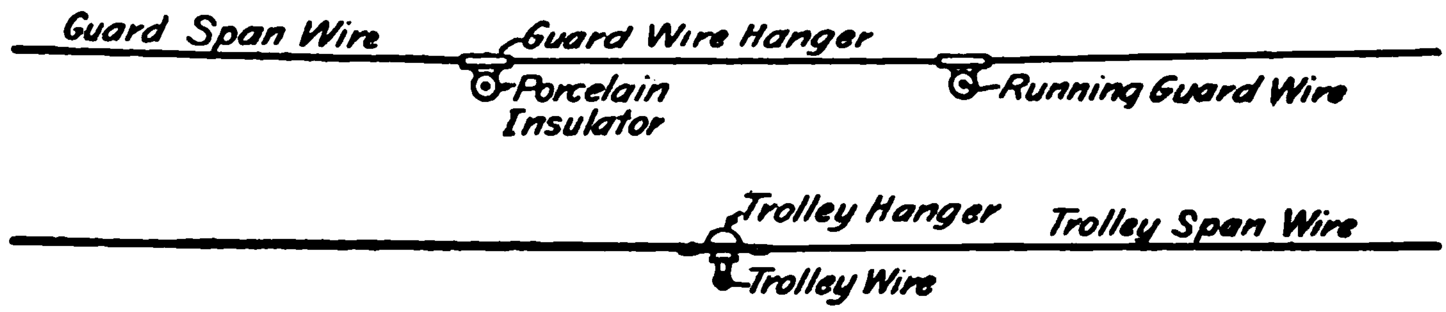


FIG. 20

are themselves apt to break and come in contact with the trolley wire. They are, however, useful in some special places, as, for example, at railway crossings. They have usually been made of No. 6 or 8 B. W. G. bare galvanized-iron wire, but it is now considered better to use weather-proof insulated iron wire, as the insulation adds much to the effectiveness of the guard.

**25. Tension on Trolley Wire.**—In putting up trolley wire, judgment must be used regarding the tension put on it. Thus, wire strung in hot weather must be allowed more sag than that put up in cold weather, otherwise the contraction will put severe strains not only on the trolley wire itself, but on the whole overhead construction. A range of 80° F. between summer and winter temperatures is not at all unusual, and this corresponds to a variation of nearly 4 feet per mile in the length of the trolley wire. For a 125-foot span of No. 0 wire, put up with a tension of 2,000 pounds, the sag at the center of the span will be, according to Mr. E. A. Merrill, 3.8 inches; for a tension of 1,500 pounds, 5 inches; for 750 pounds, 9.5 inches; for 500 pounds, 15 inches. Dawson recommends as a safe allowance for localities where the temperature does not fall below $-20°$ F., a sag equal to three-fourths of 1 per cent. of

the span when the wire is strung at the ordinary temperature of 60° to 65° F. Thus, for a 125-foot span, a sag of about $11\frac{1}{4}$ inches would be allowed, and in the warmest weather the sag would not exceed 15 inches.

**26. Span Wire.**—Span wire is usually made of galvanized iron or steel, and in the best construction, stranded wire is always used. A common size is $\frac{5}{16}$ inch in diameter, made of seven strands, No. 12 B. W. G. Where a heavier construction is desired, $\frac{3}{8}$-inch stranded wire, made of seven strands, No. 11 B. W. G., is used. Solid span wire is not desirable, but in case it is used, the size should not be smaller than No. 1 B. & S. for No. 0 trolley wire. Span wires should be placed so that the trolley wire will be from 19 to 20 feet above the top of the rail. Of course, there are places where this rule cannot be adhered to, for at steam railroad crossings the wire must be higher than 19 feet, and under elevated structures it must be much lower.

**27. Insulators.**—The hanger supporting the trolley wire is always constructed so as to provide thorough insulation, except in cases where it is used to connect the trolley wire to a feeder. With wooden poles, the hanger provides sufficient insulation between the trolley wire and ground, so that it is not necessary to insulate the span wire from the

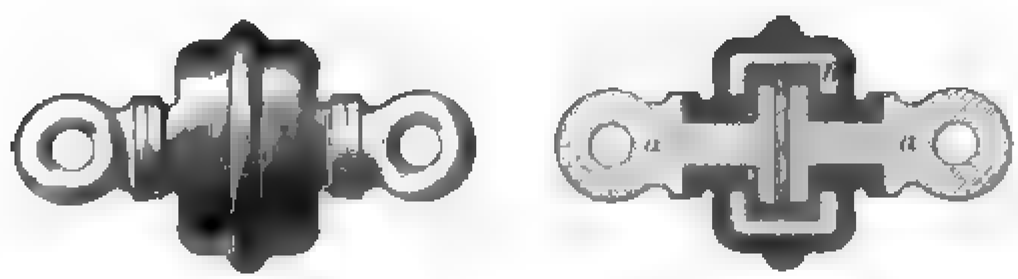


FIG. 21

poles. With iron poles, insulators are generally used in the span wire as an additional precaution. Fig. 21 shows an ordinary strain insulator much used whenever a span wire or pull-off is to be insulated from the pole. The span wires are attached to *a*, *a*, and the pull is taken up against piece *b*, which is separated from *a*, *a* by insulating material. The whole insulator, with the exception of the two eyes, is

covered with molded insulation. Fig. 22 shows two styles of insulated turnbuckle for span-wire construction with iron poles.

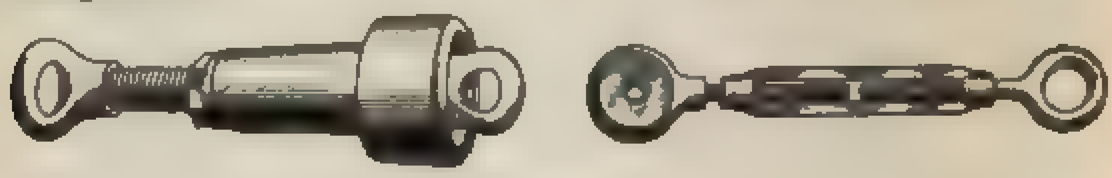


FIG. 22

**28. Trolley-Wire Suspensions.**—The hangers for suspending the trolley wire are made in a great variety of designs, but in general they consist of three parts, namely,

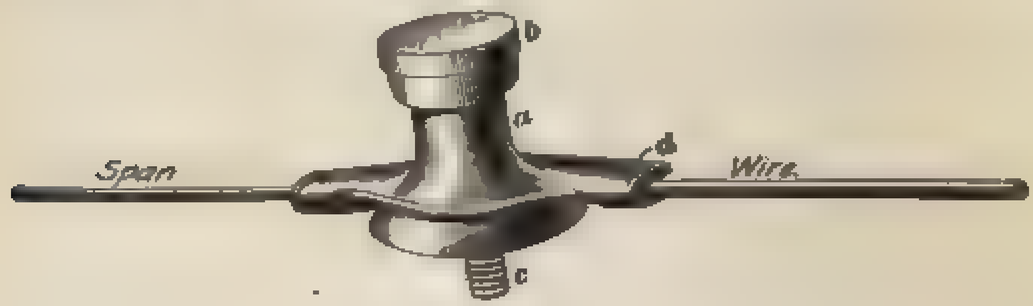



FIG. 23

a casting or body that is held by the span wire or bracket, an ear that grips or is soldered to the trolley wire, and an insulating material that separates the ear from the casting. Fig. 23 shows a common form of suspension with the ear removed; *a* is the main casting provided with the grooved extensions *d*. The span wire passes through *d* and around *a*, thus holding the hanger in place; by using a special tool, hangers are easily sprung into place on the span wire. Bolt *c* is bedded in molded insulating material and the casting is covered by a metal cap *b*. The ear to which the trolley wire is fastened screws on *c*. Fig. 24

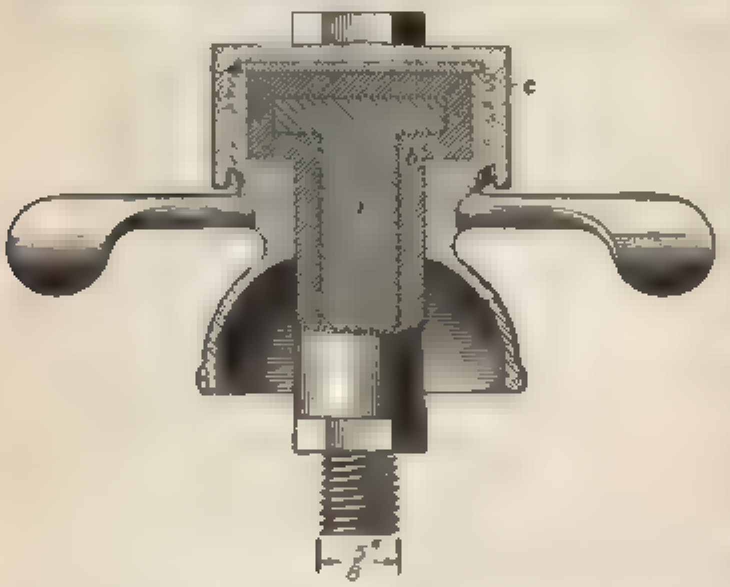



FIG. 24

is a sectional view of a hanger very similar to that in Fig. 23. The bolt *a*, with its molded insulation *b*, is held firmly in place by the screw cap *c*, but can be easily removed by unscrewing the cap.

The metal castings for overhead fittings are made either of malleable iron or brass. The ears, when soldered, are

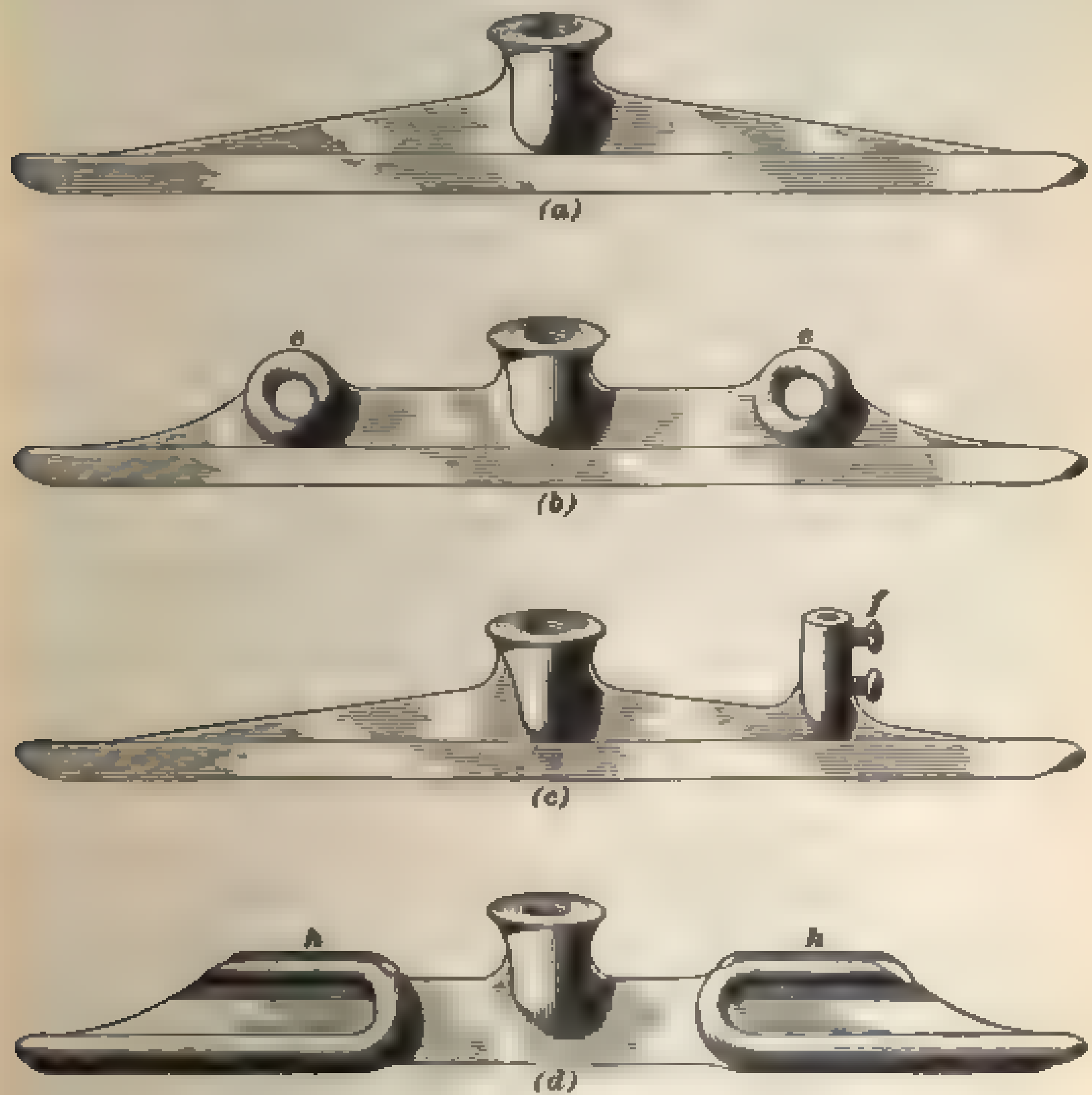



FIG. 25

made of brass; those designed to clamp on the wire are usually made of malleable iron.

Fig. 25 shows four styles of ears intended for soldering to the trolley wire. They are provided with a groove on the under side, in which the wire lies. The ear shown at (*a*) is known as a **plain ear**; it is used for ordinary straight-ahead work. (*b*) shows a **strain ear**, so called because it is provided with lugs *e*, *e*, to which the wires *a*, *a*, Fig. 17, are

the under side of a simple two-way **V** frog of a type that is largely used; (*b*) is a right-hand frog and (*c*) a left-hand frog. In these frogs the trolley wire is soldered into the ears. Fig. 30 shows a **V** frog in its natural position. In this case, the trolley wire is held by clamps *b*, *b*, *b* and no solder is necessary. The span wire is attached to the ears *a*.

**31.** It is necessary that frogs be placed correctly with relation to the track, and mechanical fastenings for the wires are therefore desirable, because they allow the frog to be adjusted to the position giving the best results. The satisfaction that any frog will give depends a great deal on how it is put up. If put up level, the trolley is very likely to follow the same direction as the car, but if allowed to sag down on one side, it will be a never-ceasing source of trouble, due to its throwing the trolley wheel off the wire. The position for the frog may be found by the method

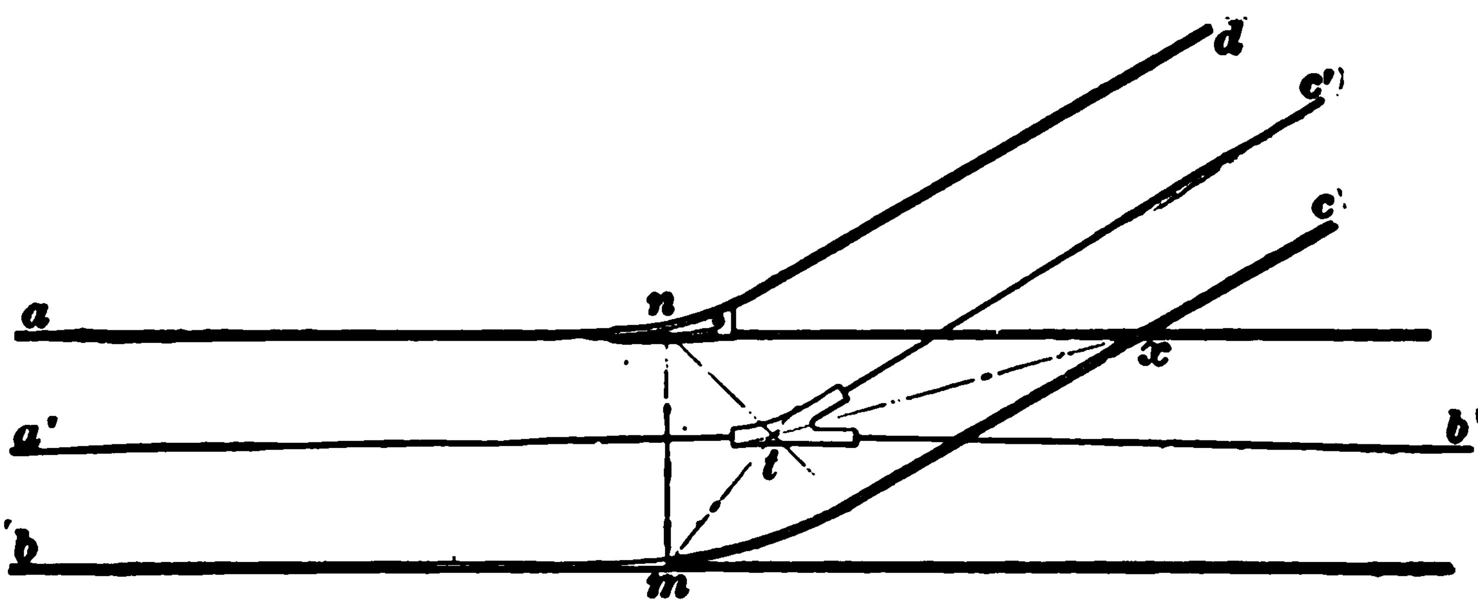



Fig. 31

shown in Fig. 31, where *a* and *b* are the main-line tracks, *c* and *d* the branch-line tracks, $a'\,b'$ the main trolley wire, and $t\,c'$ the branch trolley wire. The center of the triangle $n\,x\,m$ will be at a point *t* where the lines bisecting each angle meet; and this determines the position of the frog. It will be a little removed from the center lines of the tracks. In practice it is often found necessary to shift a frog after it has been put up in order to make the trolley wheels run over it without jumping off. Lateral adjustment can be obtained by means of the turnbuckles attached to the span

ordinary Western Union joint, Fig. 36, or by a long twisted joint, as in Fig. 37. In the latter case the insulation is removed for about 2 feet from the ends, and the wires twisted together while under tension and then soldered. This makes a good joint and it is much neater and less bulky than the Western Union when used with large solid wires, such as No. 000 or No. 0000.

FIG. 36

A solution of resin in alcohol makes a good flux for soldering such joints, as it does not corrode the wire.

Large feeder cables may be joined either by weaving the strands together and soldering or else by using a copper sleeve and thoroughly soldering the ends into it. Another effective method of joining cables is to slip a heavy copper

FIG. 37

sleeve over the joint and then subject this sleeve to very heavy pressure by means of a special portable hydraulic press. All overhead wires after being spliced should be thoroughly taped, so as to provide an insulation at least equal to the covering on the wire.

**35. Splicing Trolley Wires.**—When a trolley wire is spliced, the joint has to be mechanically strong, because there is considerable strain on the wire; also, the joint must offer as little obstruction as possible to the passage of the trolley wheel. The most common method of splicing trolley wire is by means of a tinned tapered brass sleeve, Fig. 38. The wires go in at each end of the connector and are bent up through the openings *a*, *a*. The remaining space is then poured full of melted solder and the ends of the wire trimmed off. This connector will give excellent service if care is taken to see that it is made of heavy enough material and is a good fit for the wire. (*b*) shows dimensions for a satisfactory connector for No. 00 wire.

The splicing ear shown in Fig. 25 (*d*) represents another device for splicing trolley wire. The general idea is the same as that used in the tubular trolley connector, except that it must be used at a point of support, as indicated by the lug for attaching to the hanger. The ends of the wire to be

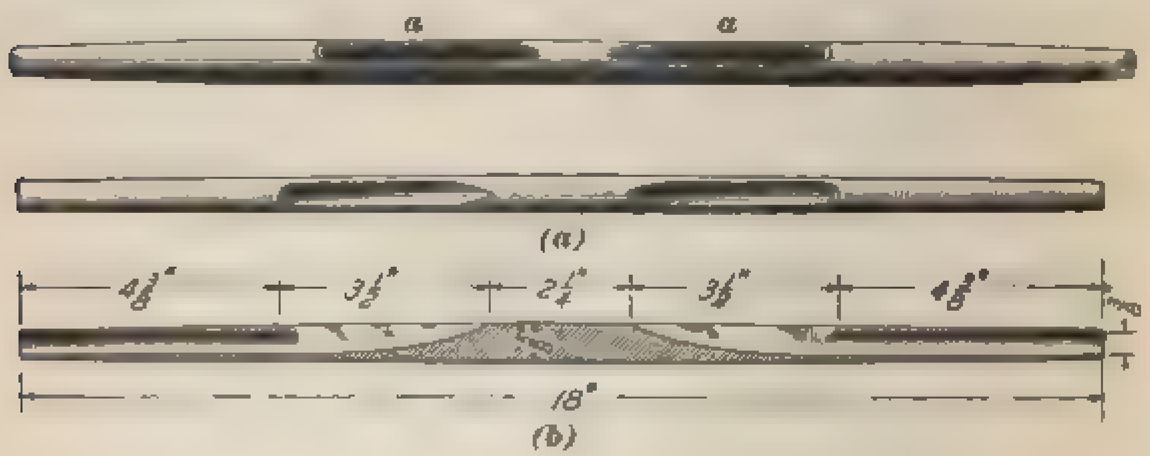



FIG. 38

spliced go into the ear at the ends, pass up through the holes *h*, *h*, and are turned back and trimmed off. The fins on the lower edge of the ear are clinched and the whole is then sweated with solder and cleaned off. Splicing ears do not always call for the use of solder; in some of them the wire is held by means of screw clamps, but they all have the disadvantage that a splice cannot be made except where there is a hanger, whereas with a sleeve connector, a splice can be made anywhere on the line.

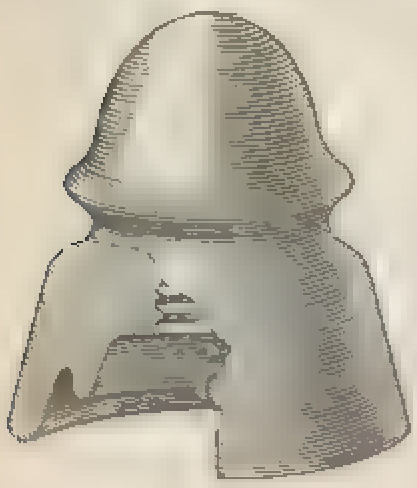


FIG. 39

**36. Feeder Insulators.**—Heavy glass insulators may be used for supporting feeders of ordinary size. In the case of large feeders, however, the strain is very great and glass insulators are liable to crack. This is especially so at curves, where the strain on the insulator may be very heavy.

Where the heavy feeder cable subjects the pole insulator to a side strain, as at corners and curves, insulators of

where there are two trolley wires and where a span wire or pull-off wire must be attached to each side of the hanger.

For suspending trolley wires and making repairs on the same, a "tower wagon" is used; this consists of a platform


Fig. 29

supported on a wagon at a convenient height for ready access to the wires. This platform is generally so arranged as to project beyond the wagon, so that the latter may stand clear of the tracks while repairs are in progress and not


Fig. 30

interfere with regular traffic. When not in use, the platform may be lowered to the wagon by means of a winch.

**30. Frogs.**—At the point where one line branches from another, overhead switches, or **frogs**, are used to guide the trolley wheel from one wire to the other. Fig. 29 (*a*) shows

**38. Line Lightning Arresters.**—The overhead distributing system of an electric railway should be liberally supplied with lightning arresters. There should be at least five to the mile and a good ground connection should be provided by connecting to the rail. The arresters used for this work are practically the same as those for indoor location in power stations, except that they are enclosed in weather-proof cases.

## THE TRACK

**39.** The **track** on which electric cars are to run must be substantially constructed. Each car carries its own motors and the track is subjected to much greater wear and tear than if the cars were propelled by some outside source of power, as, for example, on a cable road. The rails are subjected to the grinding action of the wheels whenever slippage occurs and the weight of the motors on the trucks is so great that unevenness in the track causes severe pounding. When electric railroads were first installed, the track construction was altogether too light and the whole tendency has been toward heavier construction, until at present the trackwork on the best electric railways is fully as substantial as that on trunk-line steam roads. On most electric railways, the track is used for one side of the circuit and the rail joints must therefore be of good conductivity. Special precautions must be taken to see that the joints are so made that they will not deteriorate rapidly; they should also provide a conductivity at least as good as a length of rail equal to the length of the joint, but on many roads the conductivity is not up to this standard. Rails for electric roads, as now built, seldom weigh less than 60 pounds per yard, and in most cases weigh more. Many interurban roads use rails weighing 80 or 90 pounds per yard, and for city tracks, where high rails must often be used on account of paving, the weight will run over 100 pounds per yard.

The kind of roadbed and rail to be used depends on where the road is located. If the soil has a very poor bottom, the

subwork must be more substantial than where the soil is firm or where there is rock. The construction also depends a great deal on the traffic, and in many cases on city ordinances that call for a certain class of rail.

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## RAILS

40. **Composition of Track Rails.**—Rails are always of mild steel; i. e., steel containing a low percentage of carbon, together with manganese, silicon, and very small percentages of sulphur and phosphorus. The percentages of carbon and manganese have a marked effect on the hardness of the rail; if small, the rail will be soft and its wearing qualities poor; if high, the rail will be brittle and its electrical conductivity will be low. Table V shows the limiting percentages of carbon, phosphorus, silicon, and manganese as specified for track rails for a number of prominent street-railway systems in the United States. These will give an idea as to what is considered a desirable composition for rails; it will be noted that the percentages of the different substances do not differ greatly.

41. **Cross-Section and Weight of Rails.**—Rails are always designated by the number of pounds per yard that they weigh. Thus, a rail weighing 60 pounds per yard is known as a 60-pound rail; one weighing 80 pounds per yard, as an 80-pound rail; and so on. The weight in pounds per yard divided by 10 gives the cross-sectional area, in square inches, approximately. For example, an 80-pound rail would have a cross-section of $\frac{80}{10} = 8$ square inches. We may write

$$A = \frac{W_r}{10} \qquad (1)$$

where $A$ = area of rail section, in square inches;
$W_r$ = weight of rail, in pounds, per yard.

**Rule I.**—*To find the area of cross-section of a rail, divide the weight, in pounds, per yard by 10.*

## TABLE V
### RAIL COMPOSITION

| Road | Carbon Per Cent. | Phosphorus Per Cent. | Silicon Per Cent. | Manganese Per Cent. | Sulphur Per Cent. | Remarks |
|---|---|---|---|---|---|---|
| Boston . . . . | .50 to .60 | Not over .08 | .10 to .15 | .80 to 1.00 | Not over .08 | Rails with carbon below .50 per cent. or above .62 per cent. will be rejected |
| Buffalo . . . . | .43 to .53 | Not over .10 | Not to exceed .20 | .80 to 1.10 | | |
| Denver . . . . | .46 to .56 | .10 or less | .10 or over | | | |
| Philadelphia . | .45 to .55 | Not over .10 | .20 | .80 to 1.00 | | |
| | .37 to .45 | Not over .10 | .07 to .15 | .70 to 1.10 | Not over .05 | Illinois Steel Co. standard specification for rails under 70 lb. |
| | .45 to .55 | Not over .10 | .10 to .20 | .80 to 1.00 | Not over .05 | Same for rails over 70 lb. per yard |

To find the weight of rails required per mile of single track, the following simple formula may be used:

$$W_t = 1.76\ W_y \qquad (2)$$

where $W_t$ = weight of rails, in tons, for 1 mile of single track;

$W_y$ = weight of rail, in pounds, per yard.

**Rule II.**—*The number of tons weight of rail required for 1 mile of single track is equal to 1.76 times the weight of the rail, in pounds, per yard.*

**42. Resistance of Track Rails.**—Since, in most electric railways, the track is used as one side of the circuit, it is important to know the electrical resistance of steel. The resistance of mild steel varies greatly with its composition, the harder the steel, the higher is the resistance. Track rails are selected for their wearing qualities; hence, a certain degree of hardness is essential; but where a rail is used simply as a working conductor, as in third-rail systems, it can often be made of softer steel, because the only wear to which it is subjected is that of the collecting shoes.

Extended tests made by Mr. J. A. Capp on specimens of rails obtained from different sources show specific electrical resistances varying from 6.4 to 13.2 times that of copper. A fine grade of Swedish wrought iron showed a resistance of about 6 times that of copper. It has been customary to assume, in making calculations regarding track resistance, that steel ordinarily used in track rails has a specific resistance of 7 times that of copper. However, tests show that in most cases the specific resistance is much higher than this, and to be on the safe side, 10 would be more nearly in accordance with the facts and will be so taken here.

**43. Steel for Conductor Rails.**—In most cases where roads have been operated by a third rail or from special conductor rails, as in slot systems, the rails have been rolled from material the same as used for the track. Rails rolled of special steel to secure higher conductivity would

cost too much in the majority of cases. Mr. Capp's tests show that by properly limiting the impurities in the steel there is no difficulty in securing a composition that can be made without greatly increasing the cost and that will have a resistance not over 8 times that of copper. The element having the greatest effect on the resistance is manganese, and if the percentage of this is kept down, the other impurities can be present in a considerable amount without causing a very high resistance. Chemically pure iron has a resistance approximately 4.5 times that of copper, and comparatively small percentages of impurities increase the resistance in a marked degree. Pure iron, even if it could be obtained at reasonable cost, would not be suitable for conductor rails because it would not be hard enough to stand the wear of the collecting shoes. At the same time, if a conductor rail is made with percentages of carbon and manganese lower than ordinarily used, the conductivity can be improved. Mr. Capp recommends the following composition as giving a resistance not exceeding 8 times that of copper: Carbon not to exceed .15 per cent.; manganese not to exceed .30 per cent.; phosphorus not to exceed .06 per cent.; and silicon not to exceed .05 per cent. On some large systems, for example, on the New York subway, where the length of conductor rail is sufficient to warrant the preparation of special steel, it has been used; but for ordinary roads, standard rails have in many cases been installed.

**44. Formulas for Track Resistance.**—A copper bar of 1 square inch cross-section has an area of 1,273,236 circular mils. The resistance of 1 mil-foot of commercial copper may be taken as 10.8 ohms; hence, the resistance of a bar of copper 1 square inch cross-section and 1 foot long would be $\frac{10.8}{1,273,236}$, and a bar 1 yard long would have a resistance of $\frac{10.8 \times 3}{1,273,236}$ ohms. If $W_y$ is the weight of a rail, in pounds per yard, its cross-sectional area, in square inches, is $\frac{W_y}{10}$;

and if we assume that the resistance of ordinary rail steel is 10 times that of copper, a rail having a cross-section of $\frac{W_y}{10}$ square inches will be equivalent to a copper bar of $\frac{W_y}{100}$ square inches cross-section. Hence, if the resistance of 1 yard of copper bar of 1 square inch cross-section is $\frac{10.8 \times 3}{1,273,236}$ ohms, a yard of rail of weight $W_y$ will have a resistance of $\frac{10.8 \times 3}{1,273,236 \times \frac{W_y}{100}} = \frac{.00254}{W_y}$ ohm; or

$$R_y = \frac{.00254}{W_y} \qquad (3)$$

where $R_y$ = resistance, in ohms, per yard of rail;
$W_y$ = weight of rail, in pounds, per yard.

**Rule I.**—*The resistance, in ohms, of 1 yard of steel rail is equal to .00254 divided by the weight, in pounds, per yard.*

Sometimes it is more convenient to have the resistance expressed in terms of 1,000 feet of rail. Since 1,000 feet $= \frac{1000}{3}$ yards,

$$R' = \frac{.00254 \times \frac{1000}{3}}{W_y} = \frac{.848}{W_y} \qquad (4)$$

**Rule II.**—*The resistance, in ohms, per 1,000 feet of steel rail is equal to .848 divided by the weight, in pounds, per yard.*

If the resistance per mile is desired, we have

$$R_m = \frac{.00254 \times 1,760}{W_y} = \frac{4.48}{W_y} \qquad (5)$$

**Rule III.**—*The resistance, in ohms, per mile of steel rail is equal to 4.48 divided by the weight, in pounds, per yard.*

It should be particularly noted that these formulas are based on the assumption that the steel has a specific resistance 10 times that of copper.

**45.** For a special conductor rail with a resistance 8 times that of copper the formulas would become

$$R_y = \frac{.00204}{W_y} \quad (6)$$

$$R' = \frac{.679}{W_y} \quad (7)$$

$$R_m = \frac{3.59}{W_y} \quad (8)$$

In the case of a single track, there are two rails in parallel; hence, the resistance for each unit length of track (two rails) would be one-half that given by the preceding formulas. For a double-track road (four rails in parallel) the resistance would be one-fourth that given by the formulas.

As shown later, under the subjects of rail joints and rail bonding, there is no reason why the resistance measured across, say, 3 feet of rail including a joint should not be as low as 3 feet measured across the solid rail if proper care is taken at the joints. Hence, for first-class construction, it is allowable to take the resistance calculated from the above formulas as representing the actual track resistance without the necessity of adding anything for extra resistance due to joints.

Table VI shows various values of rail and track resistance thus calculated; if provision is not made for thorough bonding, the values given would be exceeded by an amount depending on the conductivity of the joints as compared with an equal length of solid rail.

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## RAIL SECTIONS

**46.** Two kinds of rail are in common use for electric railways: **T rails** and **girder rails**; girder rails may be subdivided into two classes: *tram rails* and *groove rails*. There is no good reason why a **T** rail should not be called a girder rail; it resembles a girder fully as much as the rails commonly known by that name, and this is particularly so with the high **T** rails now so much used in paved streets.

## TABLE VI

### RAIL RESISTANCE

| Weight Pounds per Yard | Area of Cross-Section Square Inches | Track Rails (Resistance of Steel = 10 × Resistance of Copper): Equivalent Copper Cross-Section Square Inches | Track Rails: Ohms per Yard, Single Rail | Track Rails: Ohms per Yard, Two Rails in Parallel | Track Rails: Ohms per Yard, Four Rails in Parallel | Track Rails: Ohms per 1,000 Feet, Single Rail | Track Rails: Ohms per 1,000 Feet, Two Rails in Parallel | Track Rails: Ohms per 1,000 Feet, Four Rails in Parallel | Track Rails: Ohms per Mile, Single Rail | Track Rails: Ohms per Mile, Two Rails in Parallel | Track Rails: Ohms per Mile, Four Rails in Parallel | Conductor Rails (Resistance of Steel = 8 × Resistance of Copper): Equivalent Copper Cross-Section Square Inches | Conductor Rails: Ohms per Yard, Single Rail | Conductor Rails: Ohms per Yard, Two Rails in Parallel | Conductor Rails: Ohms per 1,000 Feet, Single Rail | Conductor Rails: Ohms per 1,000 Feet, Two Rails in Parallel | Conductor Rails: Ohms per Mile, Single Rail | Conductor Rails: Ohms per Mile, Two Rails in Parallel |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 40 | 4.0 | .40 | .0000635 | .0000318 | .0000159 | .0212 | .0106 | .00530 | .1120 | .0560 | .0280 | .50 | .0000510 | .0000255 | .0170 | .00850 | .0898 | .0449 |
| 45 | 4.5 | .45 | .0000564 | .0000282 | .0000141 | .0188 | .00940 | .00470 | .0995 | .0498 | .0249 | .56 | .0000453 | .0000227 | .0151 | .00755 | .0798 | .0399 |
| 50 | 5.0 | .50 | .0000508 | .0000254 | .0000127 | .0169 | .00845 | .00423 | .0896 | .0448 | .0224 | .63 | .0000408 | .0000204 | .0136 | .00680 | .0718 | .0359 |
| 55 | 5.5 | .55 | .0000462 | .0000231 | .0000116 | .0154 | .00770 | .00385 | .0815 | .0408 | .0204 | .69 | .0000371 | .0000186 | .0123 | .00615 | .0653 | .0327 |
| 60 | 6.0 | .60 | .0000423 | .0000212 | .0000106 | .0141 | .00705 | .00353 | .0747 | .0374 | .0187 | .75 | .0000340 | .0000170 | .0113 | .00565 | .0598 | .0299 |
| 65 | 6.5 | .65 | .0000391 | .0000196 | .00000978 | .0130 | .00650 | .00325 | .0689 | .0345 | .0172 | .81 | .0000314 | .0000157 | .0104 | .00520 | .0552 | .0276 |
| 70 | 7.0 | .70 | .0000363 | .0000182 | .00000908 | .0121 | .00605 | .00303 | .0640 | .0320 | .0160 | .87 | .0000291 | .0000146 | .0097 | .00485 | .0513 | .0257 |
| 75 | 7.5 | .75 | .0000338 | .0000169 | .00000845 | .0113 | .00565 | .00283 | .0597 | .0299 | .0149 | .94 | .0000272 | .0000136 | .00905 | .00453 | .0479 | .0239 |
| 80 | 8.0 | .80 | .0000318 | .0000159 | .00000795 | .0106 | .00530 | .00265 | .0560 | .0280 | .0140 | 1.00 | .0000255 | .0000128 | .00849 | .00424 | .0449 | .0224 |
| 85 | 8.5 | .85 | .0000299 | .0000149 | .00000748 | .00998 | .00499 | .00249 | .0527 | .0264 | .0132 | 1.06 | .0000240 | .0000120 | .00799 | .00399 | .0422 | .0211 |
| 90 | 9.0 | .90 | .0000282 | .0000141 | .00000705 | .00942 | .00471 | .00236 | .0498 | .0249 | .0124 | 1.12 | .0000227 | .0000114 | .00754 | .00377 | .0399 | .0199 |
| 95 | 9.5 | .95 | .0000267 | .0000134 | .00000668 | .00893 | .00447 | .00223 | .0472 | .0236 | .0118 | 1.18 | .0000215 | .0000108 | .00715 | .00358 | .0378 | .0189 |
| 100 | 10.0 | 1.00 | .0000254 | .0000127 | .00000635 | .00848 | .00424 | .00212 | .0448 | .0224 | .0112 | 1.25 | .0000204 | .0000102 | .00679 | .00339 | .0359 | .0179 |
| 105 | 10.5 | 1.05 | .0000242 | .0000121 | .00000605 | .00808 | .00404 | .00202 | .0427 | .0214 | .0107 | 1.31 | .0000194 | .00000970 | .00647 | .00324 | .0342 | .0171 |
| 110 | 11.0 | 1.10 | .0000231 | .0000116 | .00000578 | .00771 | .00386 | .00193 | .0407 | .0204 | .0102 | 1.37 | .0000186 | .00000930 | .00618 | .00309 | .0327 | .0164 |
| 115 | 11.5 | 1.15 | .0000221 | .0000111 | .00000553 | .00737 | .00369 | .00184 | .0389 | .0195 | .00973 | 1.43 | .0000177 | .00000885 | .00590 | .00295 | .0312 | .0156 |

In Fig. 43, (*a*) shows a **T** section, (*b*) a tram girder, and (*c*) a groove girder. In each case, *h* is the *head*, or *ball*, *w*, the *web;* and *f*, the *flange* or *foot*. A **T** rail is a *center-bearing rail*, because the center of the head is directly over the center of the web. The girder rail shown in (*b*) is called a *tram rail* because of the projecting tram *t*; in (*c*), the *groove o* is the distinctive feature; the projecting part *d*

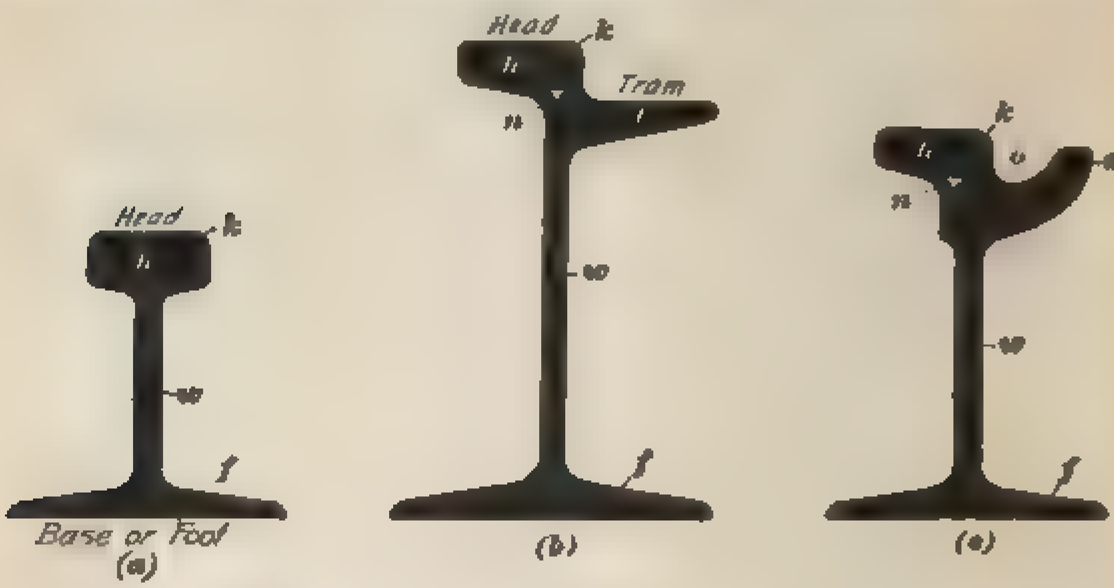



FIG. 43

is called the *lip*. *k* is the *gauge line*, or the part that the gauge touches when gauging the distance apart of the rails. The tram rail is the first in order of invention and it is still more used than any other type of girder rail. The tendency is to use long rails for electric-railway work in order to reduce the number of joints. Ordinary rails are 30 feet in length, but many roads are now using 60-foot rails even though they are more difficult to ship and handle.

**47. T Rails.**—The **T** rail is used on all steam roads and on electric roads wherever allowable. For suburban and interurban lines, it is the type universally employed; and even for city work in paved streets it is taking the place of the tram and groove rails. The **T** section gives a maximum amount of strength and stiffness with a minimum of material, and it has no groove or tram for the collection of dirt; the head remains clean, and a clean rail means less power for the propulsion of the cars. It is cheaper than the

tram or groove types and provides a track that is easier to lay and is fully as good, if not better, so far as running qualities are concerned. There has always been more or less opposition to the use of T rails in paved streets on the ground that they break up the surface of the pavement more than the tram or girder shapes, thus interfering with street traffic. However, with special paving bricks now used this objection is overcome to a large extent, and T sections are strongly advocated by many prominent street-railway engineers.

### TABLE VII

WEIGHTS AND DIMENSIONS OF STANDARD T RAILS

*(A. S. C. E. Sections)*

| Weight Pounds per Yard | Area of Cross-Section Square Inches | Width of Base and Height Inches | Thickness of Web Inches | Width of Head Inches |
|---|---|---|---|---|
| 100 | 9.8 | $5\frac{3}{4}$ | $\frac{9}{16}$ | $2\frac{3}{4}$ |
| 95 | 9.3 | $5\frac{9}{16}$ | $\frac{9}{16}$ | $2\frac{11}{16}$ |
| 90 | 8.8 | $5\frac{3}{8}$ | $\frac{9}{16}$ | $2\frac{5}{8}$ |
| 85 | 8.3 | $5\frac{3}{16}$ | $\frac{9}{16}$ | $2\frac{9}{16}$ |
| 80 | 7.8 | 5 | $\frac{35}{64}$ | $2\frac{1}{2}$ |
| 75 | 7.4 | $4\frac{13}{16}$ | $\frac{17}{32}$ | $2\frac{15}{32}$ |
| 70 | 6.9 | $4\frac{5}{8}$ | $\frac{33}{64}$ | $2\frac{7}{16}$ |
| 65 | 6.4 | $4\frac{7}{16}$ | $\frac{1}{2}$ | $2\frac{13}{32}$ |
| 60 | 5.9 | $4\frac{1}{4}$ | $\frac{31}{64}$ | $2\frac{3}{8}$ |
| 55 | 5.4 | $4\frac{1}{16}$ | $\frac{15}{32}$ | $2\frac{1}{4}$ |
| 50 | 4.9 | $3\frac{7}{8}$ | $\frac{7}{16}$ | $2\frac{1}{8}$ |
| 45 | 4.4 | $3\frac{11}{16}$ | $\frac{27}{64}$ | 2 |

**48.** For suburban or interurban roads, standard T rails similar to those used on steam roads are suitable; no paving conditions have to be met and a rail of standard height can be used. Fig. 44 shows f[illegible]r of the standard sections for T rails and fish-plates, [illegible] by the American Society of Civil Engineers [illegible] as A. S. C. E. section [illegible] all the [illegible] the width of the

base; (*a*) is a 100-pound rail; (*b*) a 95-pound; (*c*) a 90-pound; and (*d*) an 85-pound. Table VII gives dimensions of the various A. S. C. E. sections; rails as small as 45 pounds per yard are given in the table, but those lighter than 60 pounds are seldom used for electric-railway work, except perhaps for light railways around industrial plants. Many of

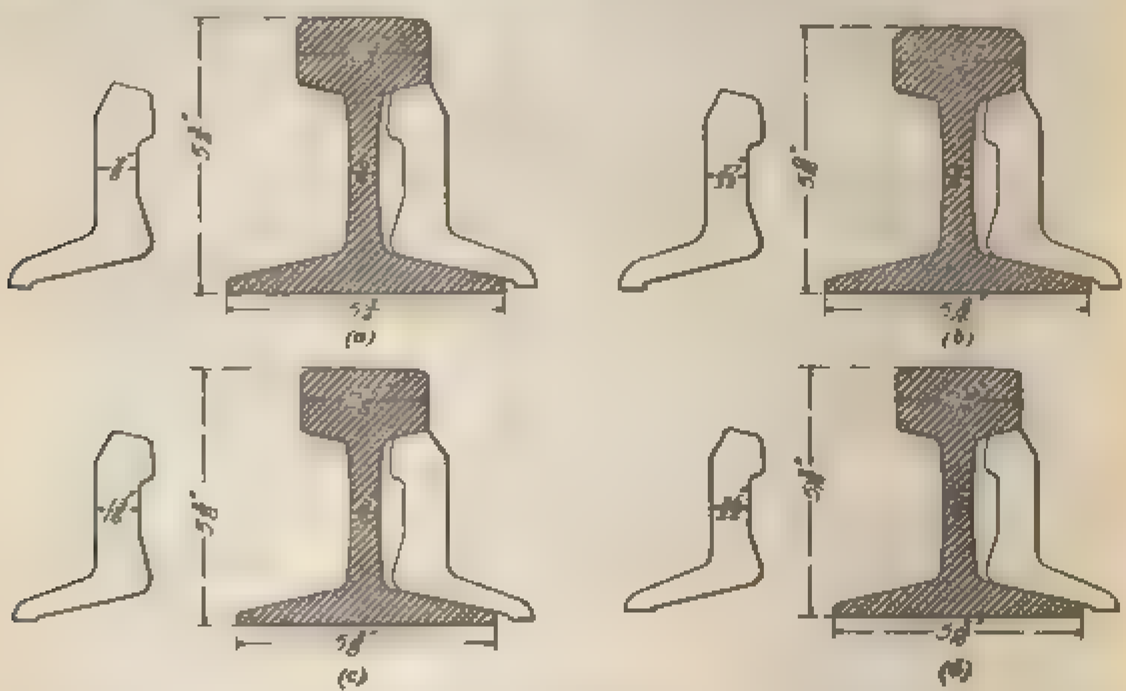
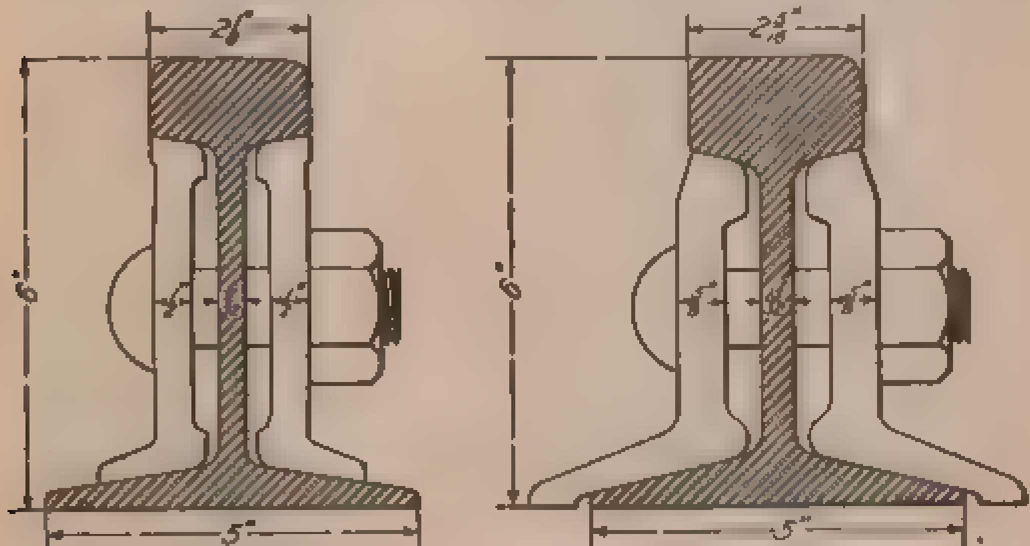


FIG. 44

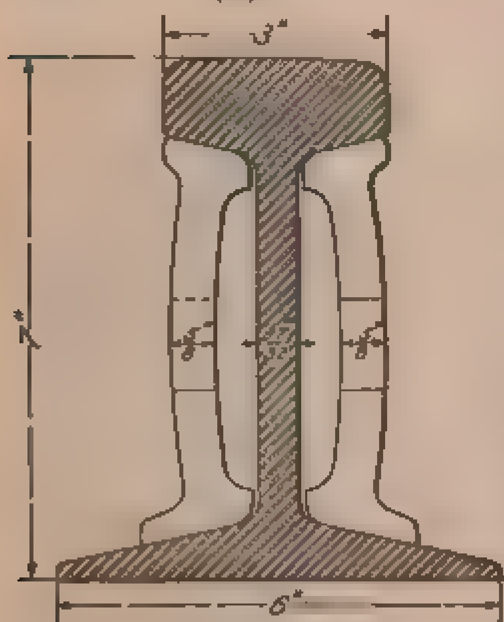
the leading interurban electric roads use rails of standard A. S. C. E. section, and unless there is some good reason for using a special section it is advisable to install a standard rail wherever possible.

**49.** When T rails are used in paved streets, it is usually necessary to lay a rail higher than the standard; therefore, T rails 6 or 7 inches in height are much used for this class of work; they are sometimes called ***shanghai rails***. Fig. 45 shows three typical high T sections: (*a*) and (*b*) are sections made by the Lorain Steel Company, (*a*) weighing 60 pounds per yard and (*b*) 72 pounds per yard. The one shown in (*c*) is recommended by the Committee on Standards of the American Street Railway Association. It weighs 95 pounds per yard and the distinctive feature is the width of tread, which is 3 inches as compared with $2\frac{1}{4}$ inches in (*a*) and $2\frac{5}{16}$ inches in (*b*). The object of the wide tread is

to allow interurban cars, having a 3-inch wheel tread, to operate over city tracks without interfering with the pavement. The splice bars, or fish-plates, are also made with an unusual amount of camber to prevent buckling when the bolts are drawn up. High **T** rails are strongly recommended,



(a) (b)



(c)

FIG. 45

by the committee just referred to, whenever the consent of the municipality can be obtained.

**50. Girder Rails.** Girder rails of the tram or groove type are intended to provide a track that will interfere as little as possible with street traffic. A groove rail leaves the street surface unbroken and there is little tendency for vehicles to run along the rails. The rail head, or groove, does not present an attractive track for carriage or truck wheels, but with the tram rail, the surface of the street is more or less broken and the tram offers a good path for carriages and trucks. The tram rail should not, therefore, be used in places where there is dense city traffic. Vehicle traffic is not of so much importance in localities where it is

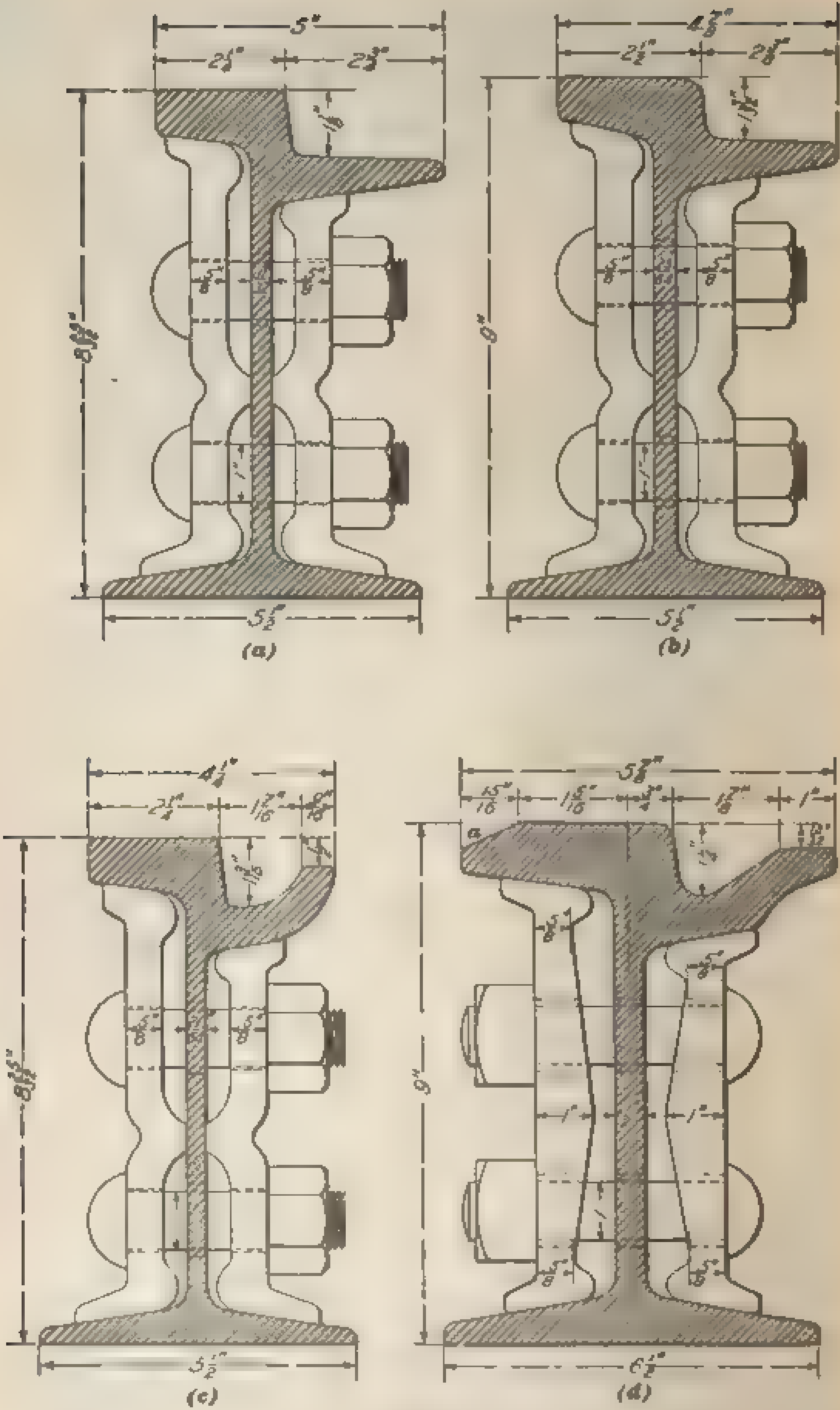



FIG. 46

not dense, but in large cities the wear on the track from this source may be considerable, and a tram rail not only attracts this traffic but makes it hard for vehicles to turn out of the way. For densely traveled districts, a grooved rail should be used; and for places where the street traffic is lighter, a high T rail with special paving bricks next the rail, as described later, will often be found preferable to the tram rail.

**51.** Fig. 46 shows four girder sections. (*a*) and (*b*) are standard tram sections; (*a*) weighs 90 pounds per yard and (*b*) 94 pounds. Groove rails can only be used satisfactorily where the streets are kept reasonably clean and where the car service is so frequent that dirt or ice does not have a chance to accumulate in the groove. The presence of foreign matter in the groove not only increases the power required to run the car, but also introduces an element of danger, as a small stone may be sufficient to throw the car off the track. It is now customary to make the groove flaring at the top, so that dirt can be pushed out sidewise by the wheel flange. Fig. 46 (*c*) shows an 88-pound grooved girder rail used in Boston. The lip is cut down $\frac{1}{2}$ inch below the tread of the rail, and the section is to a certain extent a compromise between the tram rail and full-groove rail. The groove is wide and flaring so that dirt will be forced out at the side. (*d*) shows a very heavy grooved rail used for standard trackwork in Philadelphia in localities where the traffic is dense. For places where the traffic is lighter, the section shown in (*a*) is used. The rail shown in (*d*) weighs 137 pounds per yard and the lip is extended to the right, as shown, thus combining the tram feature with the groove. Another feature is the way in which the tread is cut off at (*a*), thus helping to keep the part of the tread, on which the wheel runs, cleaner than with ordinary girder rails. For a given groove, there is always a given shape of car-wheel flange that is best suited to that groove; so that in buying car wheels, due regard must be had for the shape and size of the groove that they are to run in, otherwise

there will be excessive wear in the groove and on the wheel flange. A wheel flange must be of a certain depth in order to be safe; if the depth of the groove and the depth of the flange of the wheel are about the same, the least bit of wear in the tread of the wheel will let the weight of the car down on the flange, where it is not intended to be and which will not stand it; if the wheel flanges are deeper than the groove, the wheels cannot be used at all. A track of grooved rail must be gauged to exactness, because it offers two chances for the wheels to bind. If the gauge is too narrow, the outsides of the wheel flanges bind against the heads of the rails; if the rails are too far apart, the insides of the wheel flanges bind against the side of the groove.

**52. Standard Track Gauge.**—The standard track gauge is 4 feet $8\frac{1}{2}$ inches, as measured by means of a gauge such as that shown in Fig. 47 (*a*). The car wheels are pressed on the axle to 4 feet $8\frac{1}{4}$ inches by means of a gauge similar to that shown in Fig. 47 (*b*). To apply such a gauge correctly, one end of it should be free to move laterally about $2\frac{1}{2}$ inches, when both of the notches engage the flanges of the two wheels. T rails are much more economical from the operating point of view than girder rails, because however much the tread of the wheel may wear down or be ground down, there is nothing for the flange of the wheel to ride on.

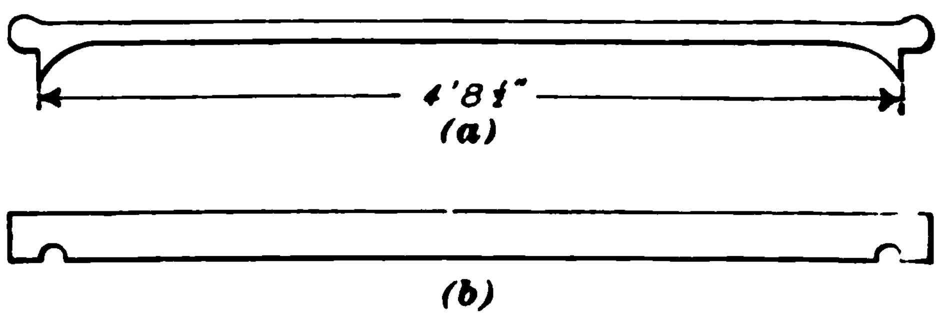


FIG. 47

**53. Rails With Conical Tread.**—The treads of wheels are conical; that is, the diameter of tread next to the flange is larger than its diameter at the outside edge. This is done to allow the car to center itself on the track when the two wheels on the same axle are of different sizes. The device probably performs its function when there is no greater difference in the wheels than is found on two wheels of the same make just as they come from the foundry; this difference

is, as a rule, not more than $\frac{1}{8}$ inch in the circumference. But the beveled tread cannot be expected to amount to very much as an equalizer where the difference in diameter of the two wheels is $\frac{3}{8}$ or $\frac{1}{2}$ inch. Such a state of affairs should not be allowed to exist, on account of the slippage it causes and for other reasons; but, unfortunately, in some cases it does exist. The general rule has been to make the top of the rail level, with the result that until there is a certain amount of wear in either the rail head or the wheel tread, the traction surface between the two is a straight line. Fig. 48 shows, in an exaggerated way, the point referred to. It is now becoming customary to roll girder rails with a conical tread, as shown in (*b*), thus providing a good traction surface between the wheel and rail from the start, and increasing the life of both by a considerable amount. The rails shown in Fig. 46 (*b*) and (*d*) have conical treads.

(*a*) (*b*)

Fig. 48

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### SPECIAL WORK, GUARD RAILS, AND CURVES

**54. Special Work.**—All roads have a number of crossings, curves, branch-offs, cross-overs, etc., and since these are different from straight track, in that they involve special care and precautions in their installation, they are all included under the general name of **special work.** Important special work is made up complete at the steel works and shipped ready to install. As the construction of special work must be carried out with great precision (a difference of $\frac{1}{4}$ inch in the angle at which one arm of a frog or crossing sticks out may cause no end of trouble), it is done step by step, as follows: The site of the proposed work is first measured up carefully and a drawing of the survey made. This drawing is then carefully checked and is used as a means to lay the work out, in actual size, with chalk on

a hard, smooth, maple floor, known as the laying-out floor; if the job checks up all right, the floor lines and angles are used as a guide for making wooden templets to be used by the patternmaker and the rail bender. When the separate parts of the job are complete, it is set up in the laying-out yard, where any slight errors or inaccuracies due to uneven shrinkage in the cast parts of the job or to want of care in the bending are detected.

**55. Designation of Special Work.**—Fig. 49 (*a*) shows a *plain curve*, in the sense that it is not complicated by any branch-offs, turnouts, or other special features; such a curve can be simple or compound, single or double, right-hand or left-hand. (*b*) is a *left-hand branch-off* and (*c*) a *right-hand branch-off;* these are used where a branch road leaves the main line. Facing the point of departure of the branch from the main line a right-hand branch-off turns to the right and a left-hand branch-off to the left. (*d*) is known as a *connecting curve and crossing;* in the figure, the curve is a right-hand branch-off to the horizontal straight track and a left-hand branch-off to the vertical one. (*e*) is a *plain* Y; (*f*) is a *three-part* Y; and (*g*) a *through* Y; the three-part Y can be used instead of a loop to turn single-end cars at the end of the line. (*h*) is a *reverse curve*, and must often be used where a cross street is broken at the main street. (*k*) is a *right-hand* and (*l*) a *left-hand cross-over*, used to cross over from one track to the other; these are very convenient devices to place here and there in a main line to turn cars back, either when they are crippled or to get them on their time after a long delay. When it is practicable, a cross-over should be put in so that its switch points will lie in the direction of travel on the two tracks. (*m*) shows a *diamond turnout;* (*n*) an ordinary *siding;* and (*o*), a *thrown-over turnout*, seen very often in temporary work, where it is of the nature of a temporary cross-over to avoid a gang of workmen.

The names given to the different parts of special work vary considerably, and much confusion results therefrom. Fig. 50 shows a piece of special work that includes an example

of nearly all the crossings, switches, etc. commonly met with, and gives the names of the various parts as recommended by the Lorain Steel Company.

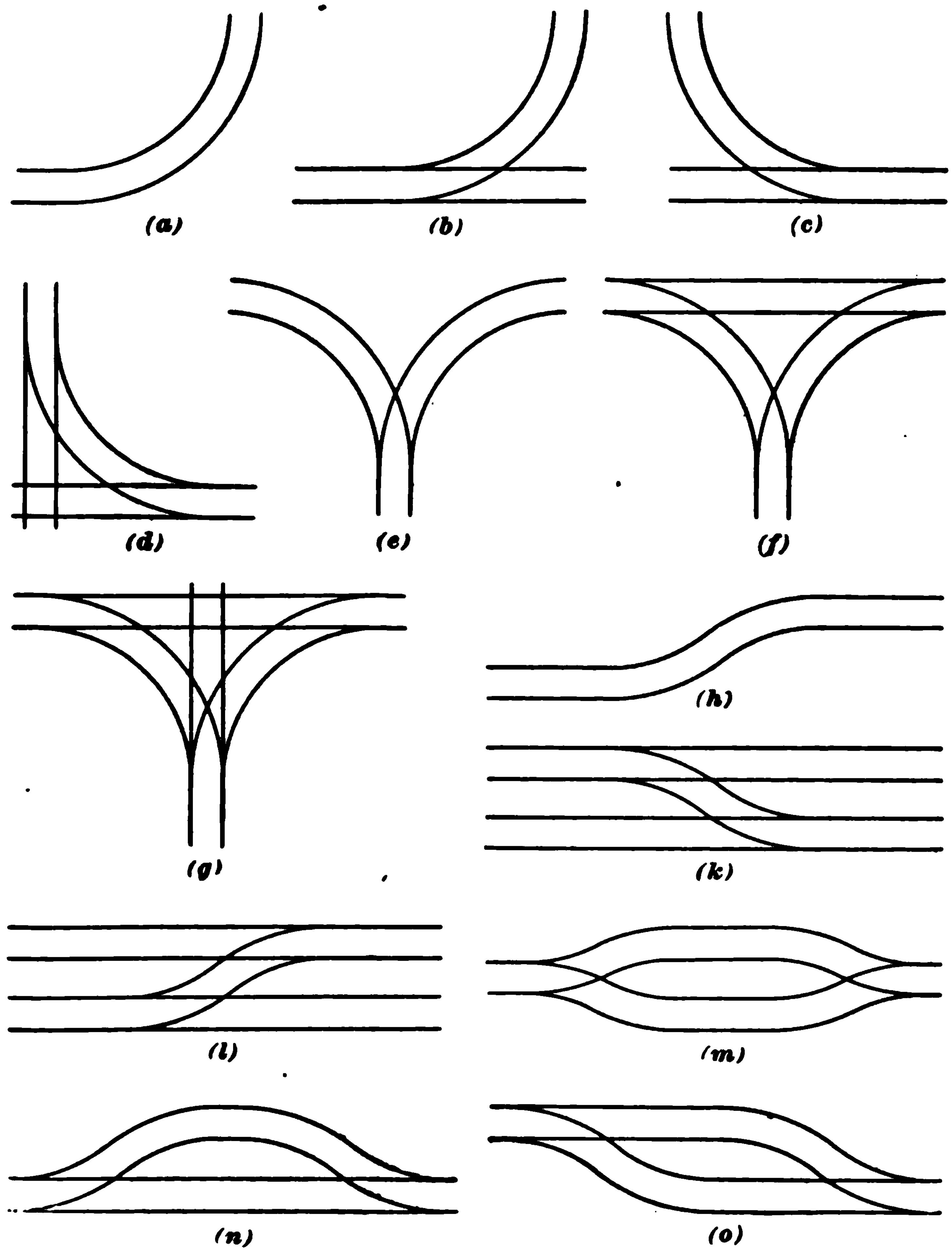
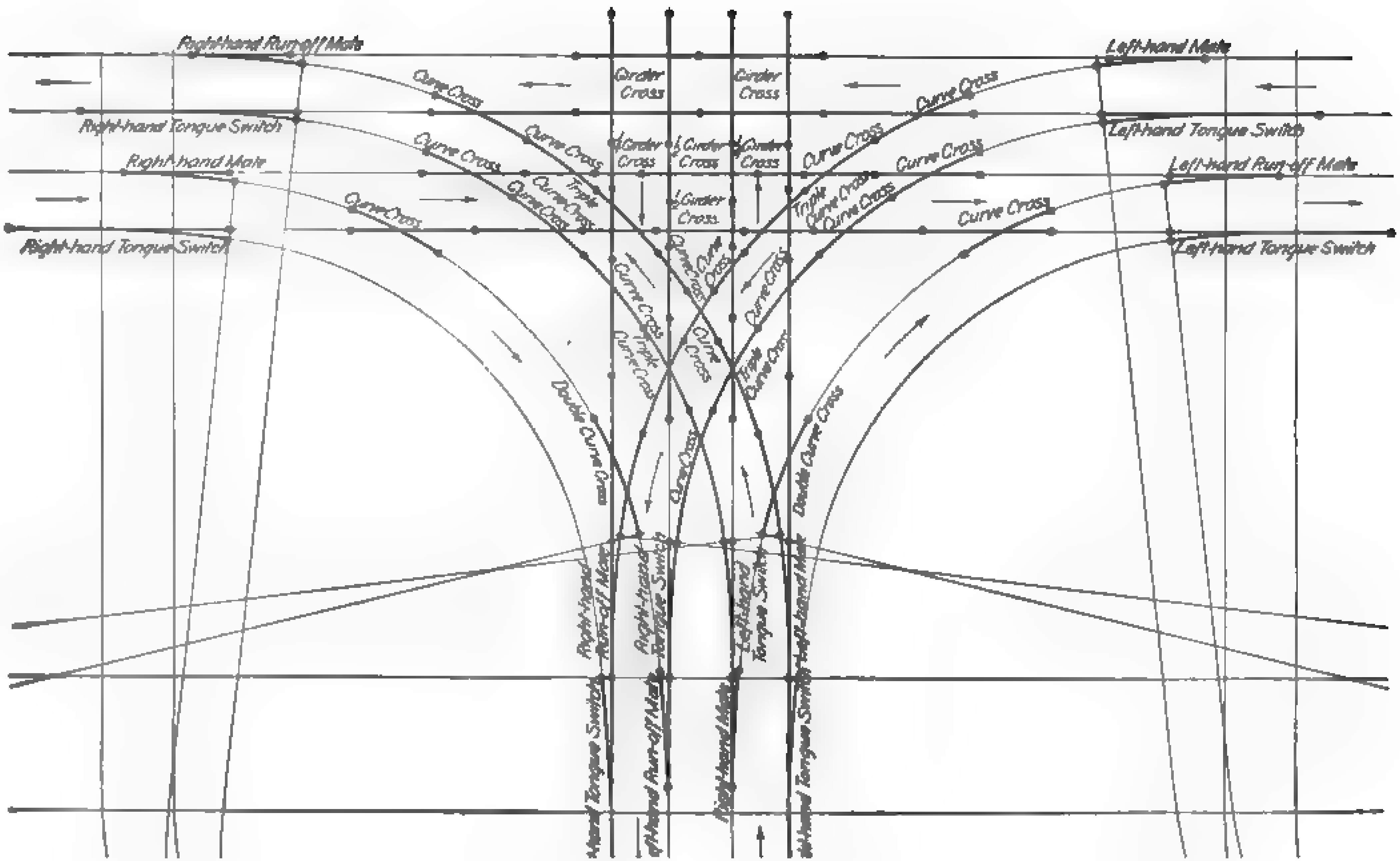


FIG. 49

**56. Construction of Special Work.**—In the switch, frog, and crossing part of the special work, the greatest wear takes place at the points and breaks, which are subjected to the pounding action of the wheels caused by the



Right-hand Run-off Mate
Right-hand Tongue Switch
Right-hand Mate
Right-hand Tongue Switch
Left-hand Mate
Left-hand Tongue Switch
Left-hand Run-off Mate
Left-hand Tongue Switch
Girder Cross
Girder Cross
½ Girder Cross
½ Girder Cross
½ Girder Cross
½ Girder Cross
Curve Cross
Triple Curve Cross
Double Curve Cross
Double Curve Cross
Right-hand Run-off Mate
Right-hand Tongue Switch
Left-hand Tongue Switch
Left-hand Mate

breaks in the tread of the rail. On this account, methods have been adopted for inserting hard steel at the points and crossings. One make of special work, known as *manganese*, takes its name from special plates of hard manganese steel that are placed at the intersections. These are held in place by special bolts, or fastenings, so that they can be renewed

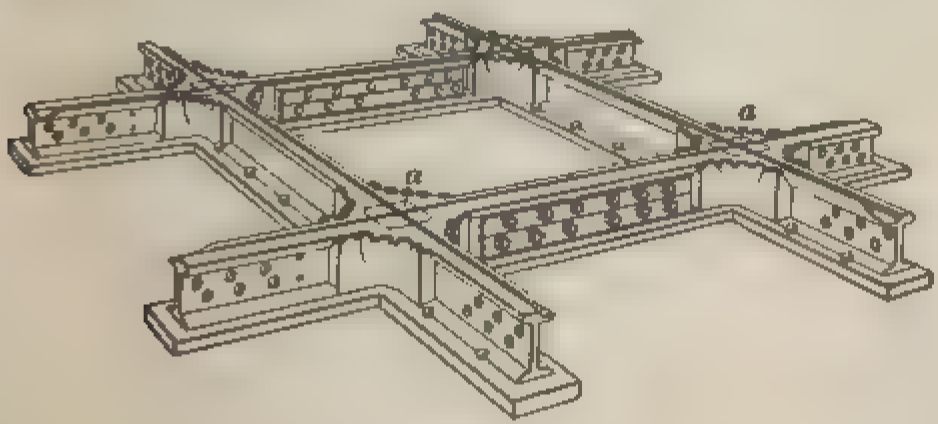



FIG. 51

when worn out. Another class of work is known as *guarantee*, because the crossings are guaranteed to wear as long as the abutting rail. In it, tempered steel wearing plates are held in place by keys, and zinc poured in around the piece. In a

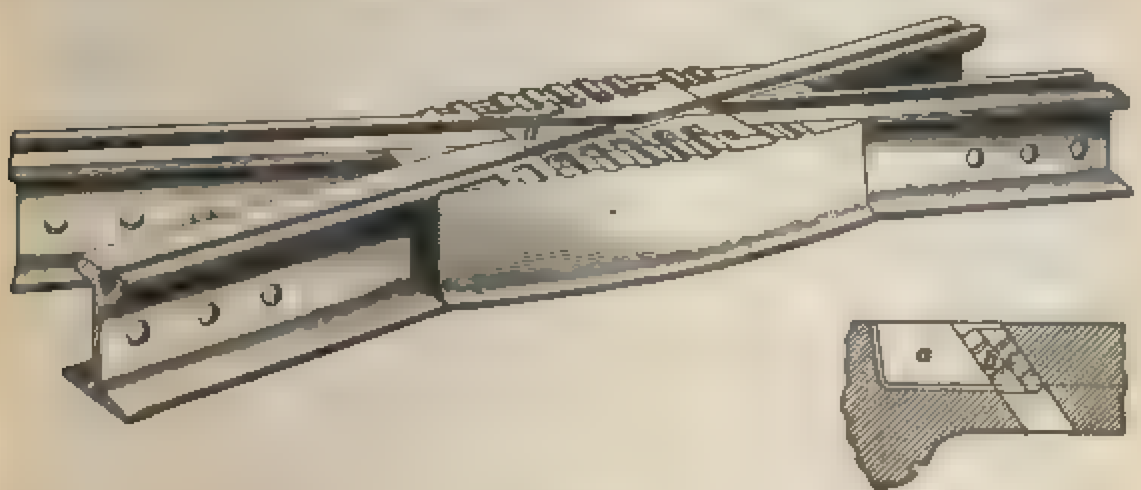



FIG. 52

third class of special work, known as *adamantine*, the crossings are made of steel castings. Fig. 51 shows a crossing of the guarantee type. Renewable hardened steel plates *a*, *a* are set in as shown; the joints are stiffened by a liberal use of cast iron, into which the ends of the rails are cast-welded at the crossings.

Fig. 52 shows a guarantee curve cross, showing how the renewable parts are arranged. The hardened-steel plate *a* is held in place by wedges *b*, *c* that are bedded in zinc, which prevents their working loose. In order to remove the plate, the wedges *b* are driven down.

**57. Curves.**—Curves are of two kinds, **simple** and **compound**, or **transition**, curves. A simple curve is one that is described with but one radius throughout its length, while a compound curve is one so constructed that the radii become shorter as the middle point of the curve is approached from either end and is easier riding than a simple curve. Street-railway curves are always designated by the radius, in feet, at the center. Long curves of light rail are sprung in, as a rule; that is, the rail is pried over with a bar and spiked into position, the paving being relied on to keep the track in place. The main objection to "springing in" a curve is, that if done on a curve of too short a radius or with heavy rail, the job in course of time will give trouble at the joints; the ends of the rails straighten out and make an angle at the joint. This means that the car trucks in rounding such a curve will change direction in jumps, instead of gradually, and impart to the car a disagreeable, jerky motion not to be found on a curve that is smooth and regular. On curves of heavy rails and moderate radius, a portable rail bender should be used, while shorter curves should be bent to a templet with a power bender. With ordinary T rails, curves having a radius of 500 feet or over can be sprung in, but with girder rails or high T rails 800 to 1,000 feet is the smallest allowable radius.

**58.** A very important point about laying out a single-track curve is to be certain that a car will go around it freely without either end overhanging the corner of the sidewalk or striking any obstruction. On double-track curves is also introduced the feature of two cars being able to pass each other without danger. It is not absolutely essential that the curves be such that two cars can pass each other on them, and in many existing cases it cannot be done. Very often,

however, it involves but small additional cost to so construct the curves, and in the long run it is the best thing to do. Whether or not a curve will allow cars to pass on it depends on the following: The length of the car; the width of the car; the amount that the ends overhang the wheel base; the distance between the track centers; the curvature; the elevation of the outside rail; the length of the wheel base; and, on double-truck cars, the distance between trucks. Also, the matter of fenders should be taken into account, as a fender increases the effective length of the car. As the trucks on a double-truck car are relatively nearer the ends of the car, the overhang in the center must be considered. The best plan is to lay out on paper and to scale a plan of the proposed curve; then, by means of a pasteboard dummy that scales the dimensions of the outside lines of the car, the actual clearance at all points can be readily determined. The positions of the car wheels may be indicated by holes through which the track can be seen, or transparent paper may be used, so that the dummy can be made to take the right path around the curve. Another point to be looked after in cutting out a dummy is to see that the widest part of the car is represented. To insure some degree of safety to the heads and arms of passengers, the clearance on both sides of the car should be at least 12 inches, if they are to pass each other on curves. Special attention must be paid to this feature where the center-pole method of line construction is used. There are many roads on which the curve clearance is not over 2 or 3 inches, but in most of such cases there is a rule against passing on curves.

**59. Transition, or Compound, Curves.**—These curves are formed by combining curves of different radii, so that the entrance of the car into the curve shall be gradual, and a sudden shock avoided. The curve at the point where it branches from the straight part of the track, or a tangent, as it is called, is of long radius and the radii are gradually decreased until the radius [illegible] center of the curve is reached. Theoretically, [illegible] method would be to

make a true spiral connection between the tangent and the center of the curve, but this would be impracticable. Steel companies making a specialty of trackwork for electric railways have developed standard transition curves that approximate a spiral sufficiently close for all practical purposes. For example, the Lorain standard curve for a radius at the center of the curve varying from 40 feet to 62 feet 6 inches has an entrance radius of 432 feet.

At one time, curves for electric railways were made up of arcs of different radii struck from three or five different centers, thus giving a rough approximation to a spiral. Curves as now used are made up of a number of radii such that the length of arc of any one radius is not over 5 feet. This gives a curve that is practically as smooth riding as a true spiral.

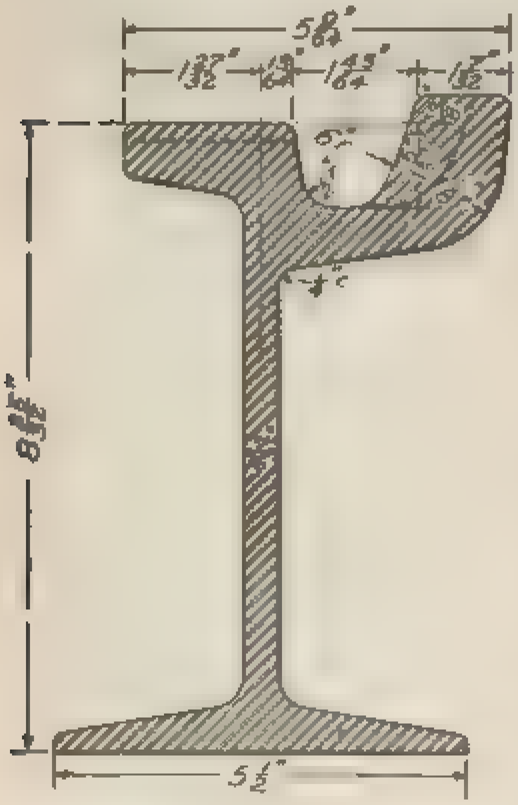
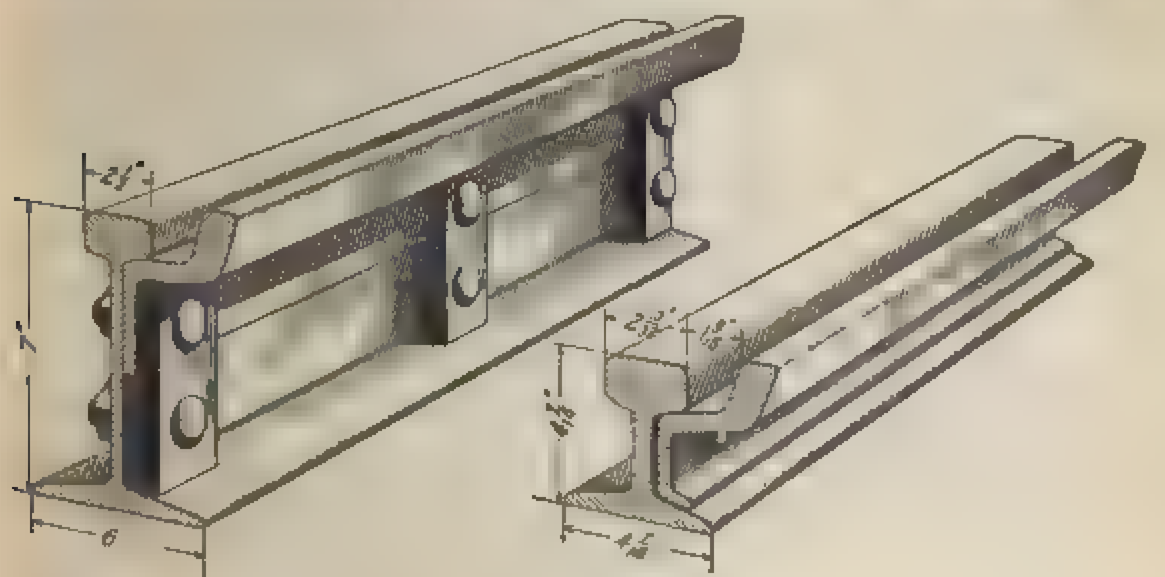


FIG. 53

**60. Guard Rails.**—Guard rails are rails provided with a protecting flange to prevent a car from climbing the rail on a curve; they may be solid or built up. Girder rails are, as a rule, solid, T rails are built up. Fig. 53 shows a section of a girder guard rail. It resembles a groove rail very closely except that the lip is heavier and projects above the tread of the rail. There is always considerable wear on the side of the groove and in time the lip and tread become worn, as shown by the dotted line. The T rail need only be provided with a regular guard where it is used in a paved street. In country work, the steam-road practice of laying a second line of T rail next to the inside-track rail is adopted. This practice is also adopted, as a rule, on bridges, where the guard rail is laid beside both track rails. The best authorities are inclined to the belief that a guard rail on

the inside, or short rail, of a curve affords ample protection, but it is common to see a guard on both the inside and outside rails of short curves. At any rate, it is not safe to rely on the wheel flanges alone to keep the car on the track, for



(a) (b)
FIG. 54

car wheels in street-railway service, on account of the heavy weight attached to the axle and also on account of the nature of the special work that they have to jolt over at times, are addicted to the trouble of broken or chipped flanges. A wheel with such a defect in the flange is almost certain to climb the rail if that wheel is on the front end of the car as a leader. As in the case of an ordinary grooved rail, a great deal of judgment must be used to select a groove that is adapted to the flanges of the wheels used. Fig. 54 shows two methods of attaching rail guards to T rails, (a) being used for high T rails and (b) for an ordinary rail, in this case a standard 65-pound A. S. C. E. section.

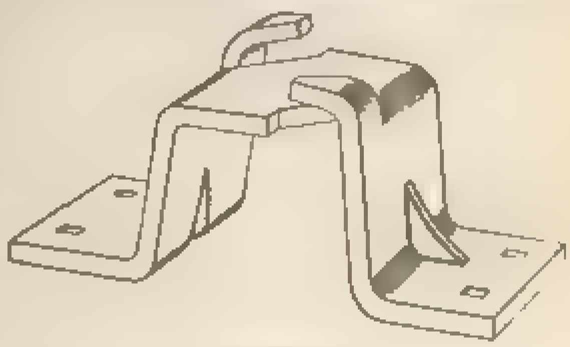
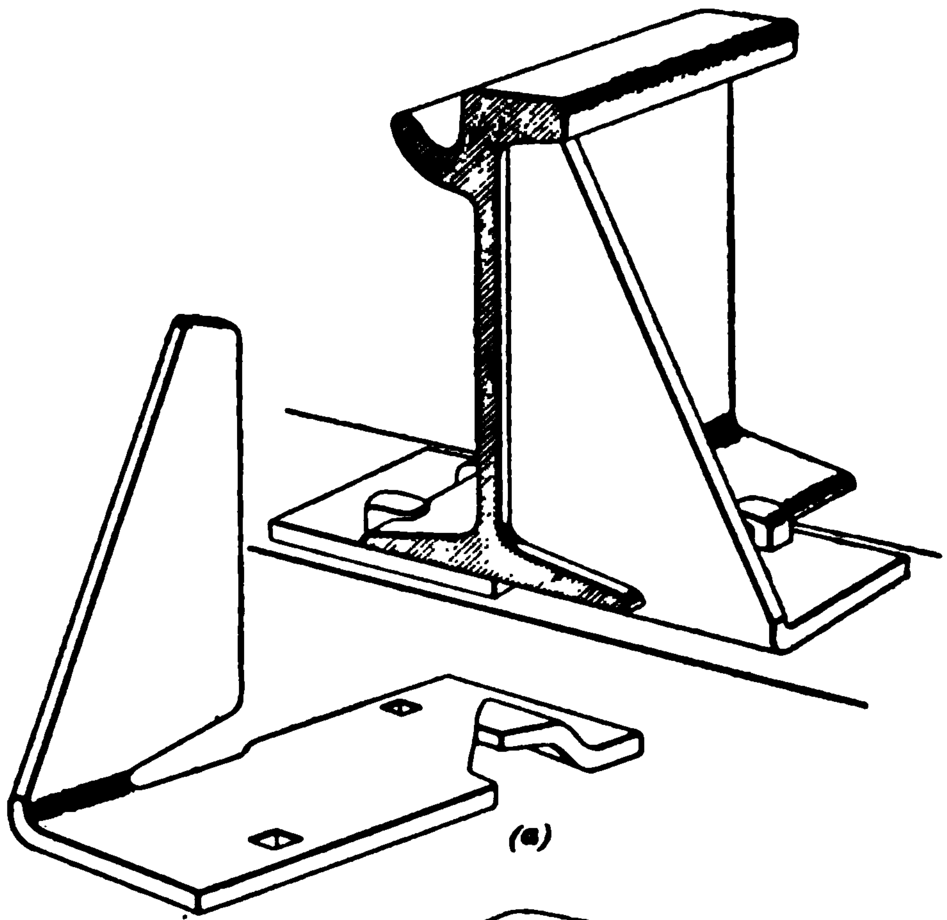
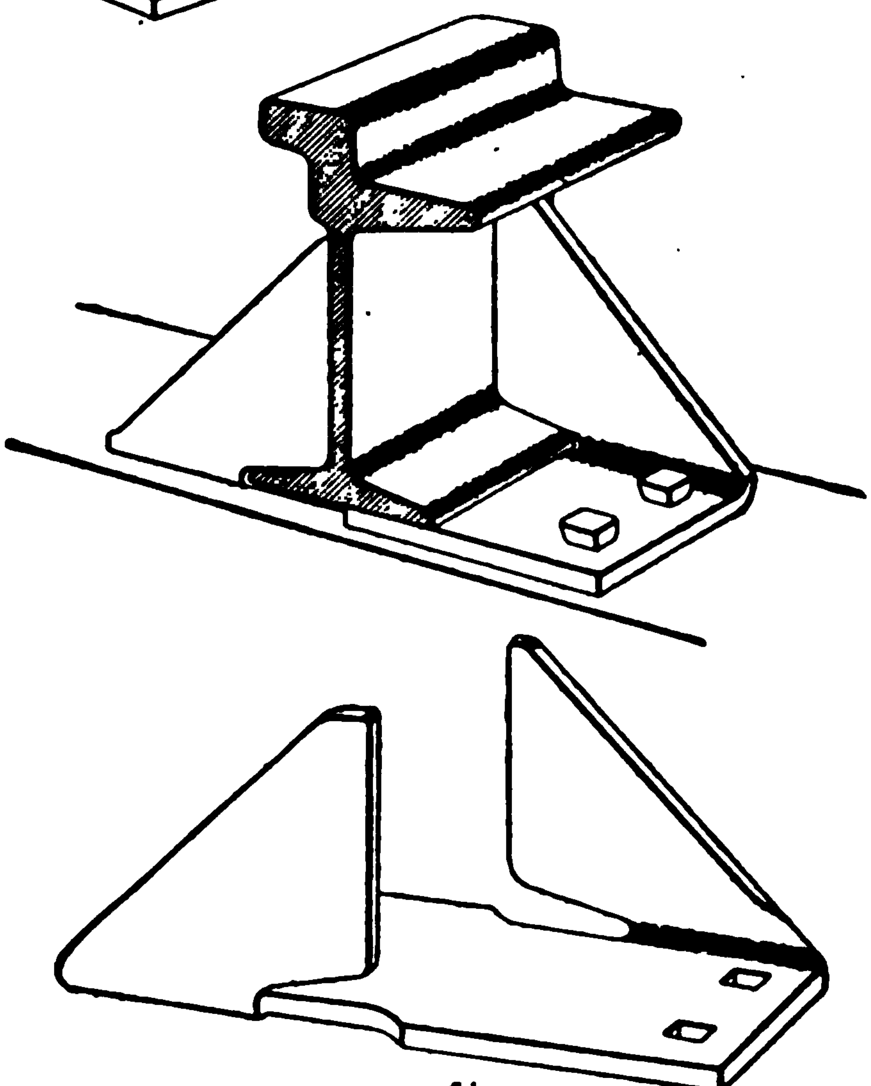


FIG. 55

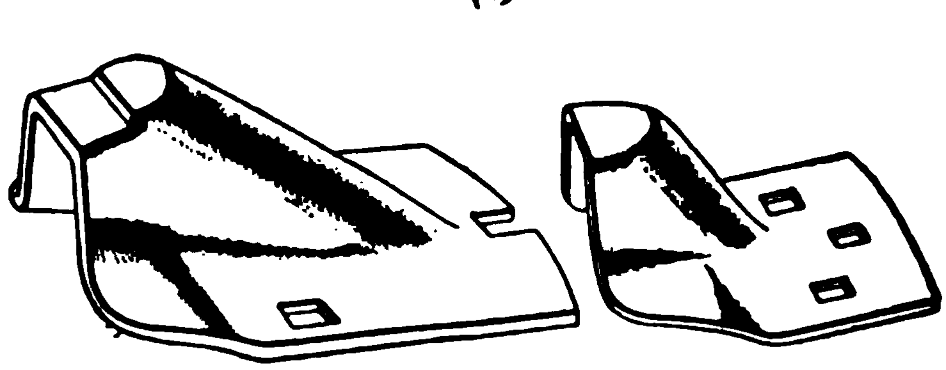
**61. Rail Chairs and Braces.**—When a rail is not deep enough to accommodate the paving in a street, it can be raised on **chairs.** These are forged fittings on which the



(a)



(b)



(c)

Fig. 56

rail rests and which raise it to the desired height. Fig. 55 shows a common form of chair.

In order to keep the track from spreading, either **tie-rods** or **braces** may be used. The former consist of rods threaded on each end; the most common form is 1½ inches by ⅝ inch forged ¾ inch round on the ends and threaded. The threaded ends pass through the webs of the rails and the track is held to gauge by nuts screwed up against the webs.

The track can also be held to gauge by means of tie brace plates that bear against the outside of the rail. These are, by many, considered a very much better form of fastening than tie-rods because they support the head of the rail and do not tend to cant the rails. They are particularly useful for holding rails to gauge on curves. Fig. 56 shows three common styles of forged brace plates, the small plates shown in (*c*) being designed for **T** rails.

# LINE AND TRACK

(PART 2)

## RAIL JOINTS

**1.** No part of electric-railway track construction calls for greater care than the track joints; in fact the life of a track is in most cases limited by the life of the joints. If there is the slightest unevenness or looseness, the pounding action soon flattens the rails at the ends and matters rapidly go from bad to worse. Again, poor joints usually imply poor electrical connection between abutting rails so that in

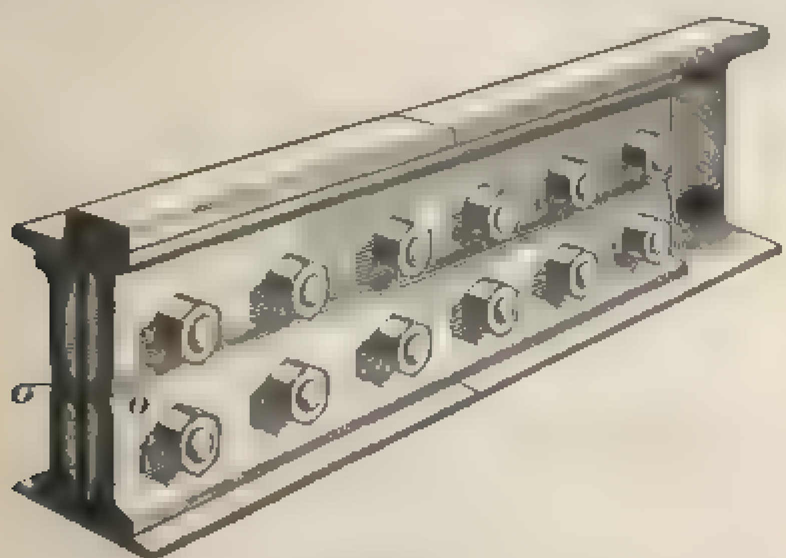


FIG. 1

electric railways, where the track is used as one side of the circuit, good joints are of even greater importance than on steam roads. Electrical contact may be made between the rails by means of copper bond wires or other bonding appliances, but if the joint is not good mechanically the continual movement and jarring will, sooner or later, impair the bond contacts. A great many kinds of rail joint have been

devised, but it will be possible to describe here only a few of the more important ones.

**2. Fish-Plates or Splice Bars.**—Fig. 1 shows a standard 12-bolt joint made with two **fish-plates, splice bars, joint plates,** or **channel plates,** as they are variously called. The plates are provided with projecting ribs *O, O*, to prevent buckling when the bolts are drawn up, while flanges at the top and bottom bear against the under side of the head and tram and the upper side of the foot, thus adding to the stiffness of the joint.

**3. Base-Supporting Joints.**—In order to provide additional strength and stiffness, a number of rail joints have been devised which, in addition to the support furnished by well-fitting joint plates, provide additional support under the foot of the rail. They are somewhat higher in first cost than ordinary splice bars, but they furnish a strong joint and are much used.

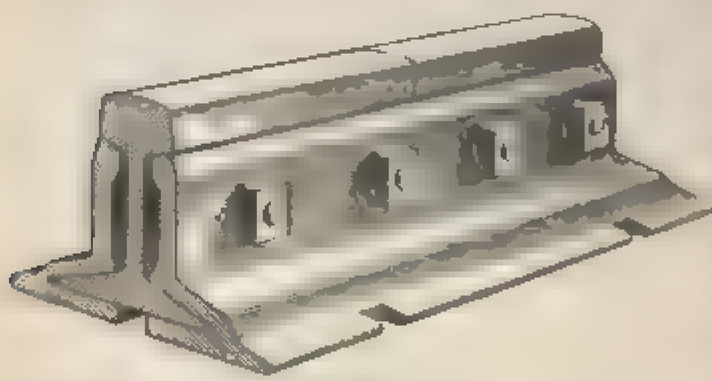


FIG. 2

Fig. 2 shows the **continuous joint,** which is made of rolled sections so shaped that a flange projects under the rail from each side, thus adding to the stiffness and holding the abutting rail ends firmly in line. Fig. 3 shows the **Atlas joint** made of ribbed steel castings; in addition to the usual rail bolts, it has two bolts on the under side. Fig. 4 shows

FIG. 3

the **Weber joint;** it is made of two channel plates very similar to those ordinarily used, while in addition a rolled angle is bolted on one side and projects under the foot of the rail. The space between the angle iron and splice bar is filled with a piece of well seasoned Southern pine that provides a certain amount of elasticity and thus takes up the looseness due to wear on the bearing surfaces of the channel plates caused by small relative movement between the plates and rail.

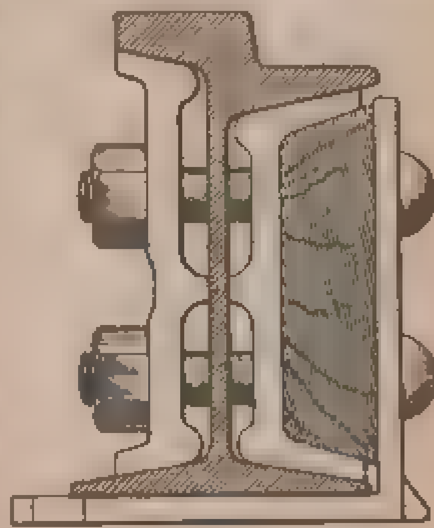


FIG. 4

4. **Rail Expansion.**—Rails are subjected to considerable variations in temperature, which cause corresponding changes in their length. On ordinary steam roads or on electric roads run where there is no paving, expansion is allowed for byplay in the track bolts. Thus, in cold weather there will be a gap of perhaps $\frac{1}{4}$ to $\frac{5}{16}$ inch between the rail ends while in warm weather there will be scarcely any space at all. Mild steel expands .0000065 of its length for each degree Fahrenheit increase in temperature. Assuming that the extreme difference in temperature that the rail is subjected to is 100° F., a track would be $.0000065 \times 100 = .00065$ of its length longer in the hottest weather than in the coldest.

A stress of 1,000 pounds per square inch will stretch a mild steel bar .00003 of its length. Hence, if a rail is stretched .00065 of its length, the stress in the rail will be $\frac{.00065}{.00003} \times 1{,}000 = 21{,}666$ pounds. If the rails are continuous and firmly anchored so that there is no play at the joints, the track as a whole must expand and contract. The rails will expand with increase in temperature, thus causing compressive stresses, and on contracting with decrease in temperature, the rails will be stret[illegible] the stresses so caused will not exceed 22,000 [illegible] square inch under the cond[illegible] assumed. A [illegible] the elastic

limit of steel is 40,000 pounds per square inch; i. e., steel subjected to any stress below this amount will not take a permanent set but will return to its original length when the stress is removed. If, therefore, a track is located so that it cannot buckle sidewise and get out of line, there is no objection to butting the ends of the rails together and fastening them by means of some form of joint that allows no longitudinal motion whatever. In paved streets this condition is met and it is now a very common practice to use methods of rail joining that give a continuous rail.

In paved streets, the rails are not subjected to such rapid or extreme variations of temperature as on open tracks, because the paving equalizes the temperature to a certain extent. There are a number of types of solid joint, the most important being the *cast welded*, the *electrically welded*, the *thermit*, and the *zinc*. The use of these is confined to paved streets, in cities, where the rails cannot get out of alinement and where the traffic is heavy enough to warrant the expense of such joints. For open trackwork they are not allowable, because provision must here be made for expansion and, even neglecting this, the expense of solid joints would be too great in most cases.

**5. Cast welded joints** are made by molding cast iron around the abutting ends of the rails, which are first thoroughly cleaned for a distance of 6 or 8 inches, on each side of the joint, by means of a sand blast. A cast-iron mold is then clamped around the rail ends and iron poured in, thus forming a joint, as shown in Fig. 5, where *l* is the cast iron molded around the rail ends.

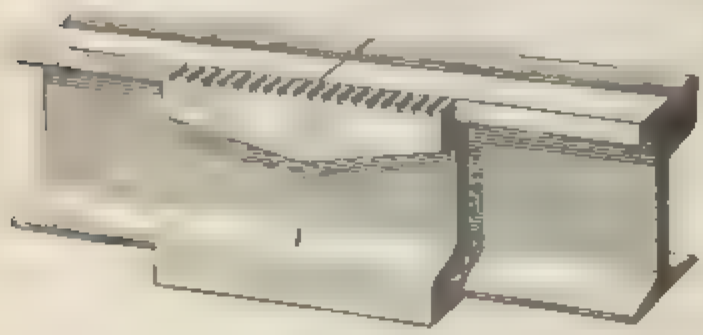


Fig. 5

In order to make these joints, considerable apparatus is required: a portable cupola is needed for melting the iron, and there must also be a sand blast for

cleaning the rails. To make the joints at all reasonable in price, a large number must be done at a time. The weight of iron varies from 70 to 225 pounds, depending on the shape of the joint and the section of the rail.

Fig. 6 shows one form of Falk joint; the sides of the cast-iron part are straight, thus making the joint much easier to pave around than when the sides are curved. The weight of iron in the joint shown in Fig. 6, which represents one of the heavier types, is about 170 pounds. In cast welding, the iron is poured at high temperature and it appears to fuse into the surface of the steel rail, thus forming a joint that is strong mechanically and of high conductivity. The conductivity of the joint, as compared with an equal length of rail, depends to

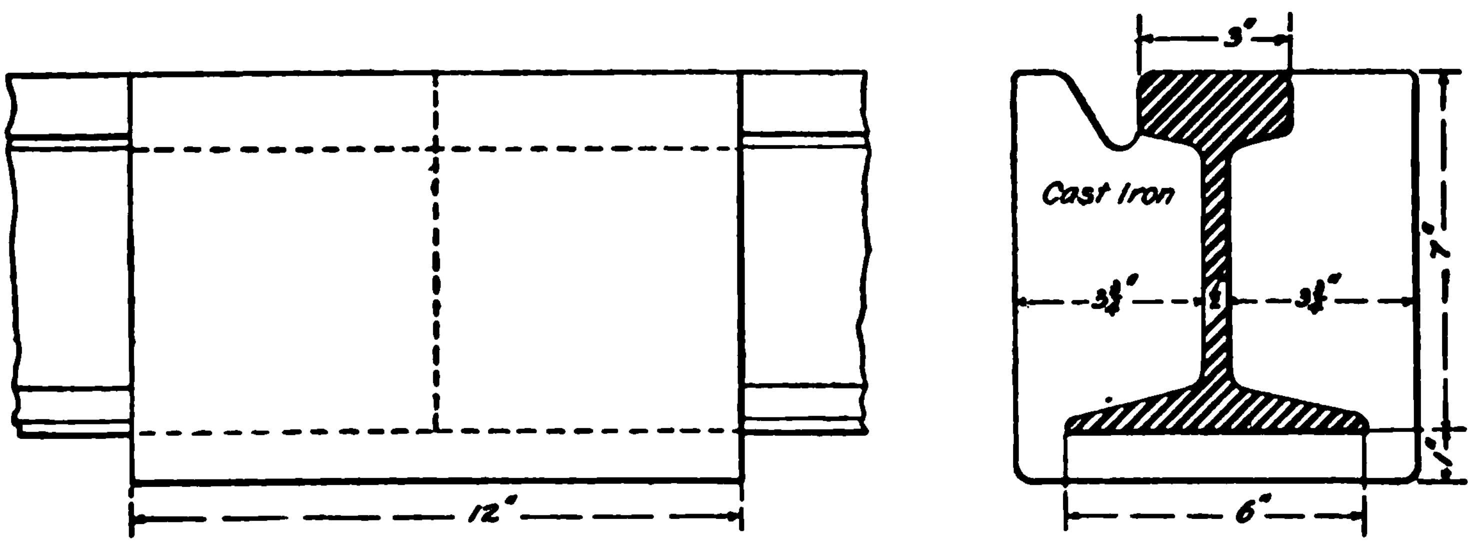



FIG. 6

some extent on the amount of iron used. In some cases the joint resistance may be about 10 per cent. higher than that of a corresponding length of rail, while in others numerous tests have shown that the resistance is as low or even lower than that of the rail. It is claimed by some that cast welding anneals the ends of the rail, thus softening them and causing them to pound or flatten out more than the rest of the rail; but on a number of roads where the cast welded joint has been used for several years no bad effects from this source have been noted.

**6. Electrically Welded Joint.**—The method of making electrically welded joints as carried out by the Lorain Steel Company consists in welding bars to each side of the web of the rail by passing a very large current through the bars and

rail. Quite an elaborate outfit is required for this process and, like cast welding, it is only applicable where a large number of joints are to be made. The outfit consists of four cars: first, a sand-blast car; second, the car carrying the welder; third, a car attached to the welding car and carrying the transforming apparatus for supplying the welder with current; fourth, a car provided with machinery for grinding off the rail treads after the joints have been welded; the cars are arranged in the order named. The

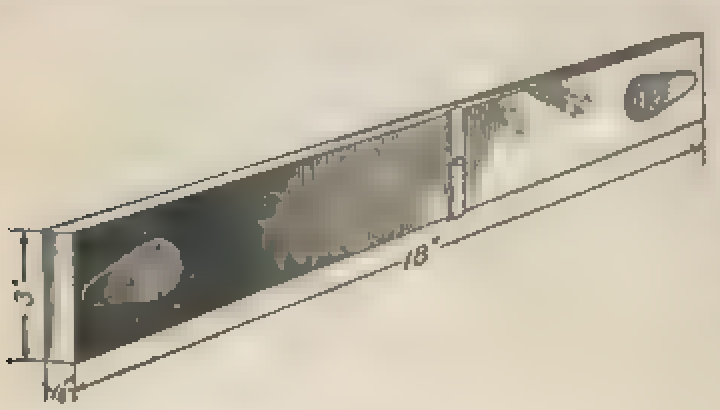



FIG. 7

first car contains a sand-blast tank and a motor-driven air compressor for operating the blast by means of which the web of the rail and the surfaces of the plates are thoroughly cleaned before the welding action takes place. To make the joint, a mild-steel plate, similar to that shown in Fig. 7, is welded on each side of the web; the finished joint appears as shown in Fig. 8. Each bar is welded in three places corresponding to the raised parts *a*, *b*, *c*, Fig. 7. The bosses *a*, *b* at the ends of the bar are formed under a drop hammer, which forces the metal in on one side and out on the other, the depression in one side being afterwards filled with a

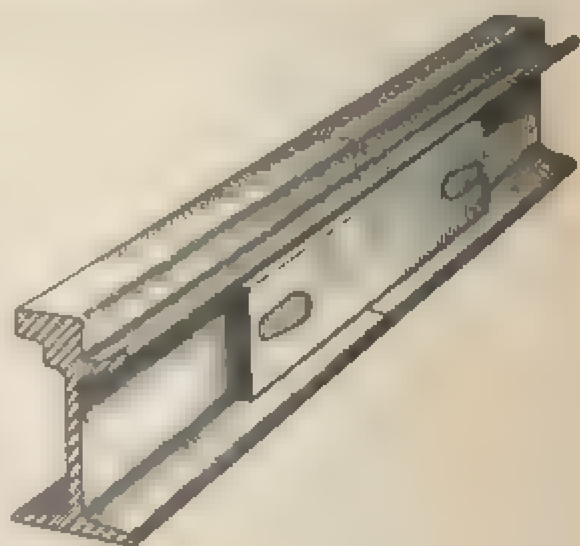


FIG. 8

piece of metal. The boss at *c*, which comes opposite the joint between the rails, is made by placing a small strip of steel over the bar. The object of the bosses is to localize the welding current and thus confine the welding to a certain area; each boss has an area of about 3½ square inches so

that the welded area on each bar is about $10\frac{1}{2}$ square inches, or 21 square inches for the two bars. After the rails have been cleaned, lined up carefully, and the bars wedged in position, the joint is ready for welding by means of the electric welder suspended from the front of the second car.

**7.** The operation of welding will be understood from Fig. 9, which shows the main parts of the welder and their relation to the joint. The two splice bars *a*, *a* are located so that the center boss comes opposite the end of rail *b*. The terminals *c*, *d* of the welding transformer *e* are pressed against the splice bars by means of levers *f*, *g* that are pushed apart at their upper ends by pistons working in a hydraulic cylinder *h*. Just sufficient pressure is applied to hold the bars in place and provide good contact. The secondary of the transformer consists of a single loop of very heavy conductor, so that a very large current at low pressure is delivered. The whole welding apparatus is suspended from a yoke *k* carried by an arm *l* extending from the front of the car and arranged so that the welder can be moved in any direction to permit an easy and rapid adjustment to the joint. The primary of the transformer is supplied with alternating current obtained from a rotary converter located in the third car and driven by direct current from the trolley. Suitable regulating devices are provided so that the voltage applied to the welder can be maintained fairly constant, even though the trolley voltage varies considerably.

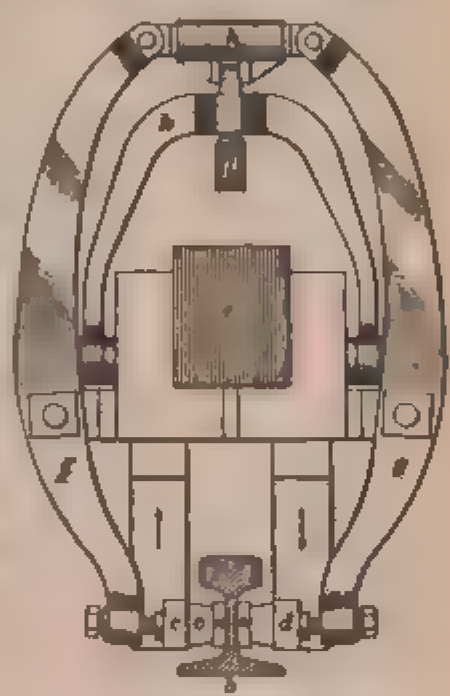


Fig. 9

The weld in the center of the ba[illegible] first. In about $2\frac{1}{2}$ minutes after the current is tu[illegible]int is brought up to a welding h[illegible] the curre[illegible] off and the pressure on the jo[illegible]creased [illegible] cylinder *h*,

the total pressure applied being about 37 tons. After a few moments, the pressure is released and the welder adjusted to one of the end welds where the process is repeated, only with both end welds, the heavy pressure is maintained until the metal has cooled below a glowing heat; it has been found that this makes the weld tougher. Since the middle weld is made first, the bars become expanded because of the heat, and since the end welds are made before the middle weld has cooled off, the ends of the bars are fastened to the rail while the metal is expanded. Hence, as the bars cool, the ends of the rail are pulled together, thus making a very close joint.

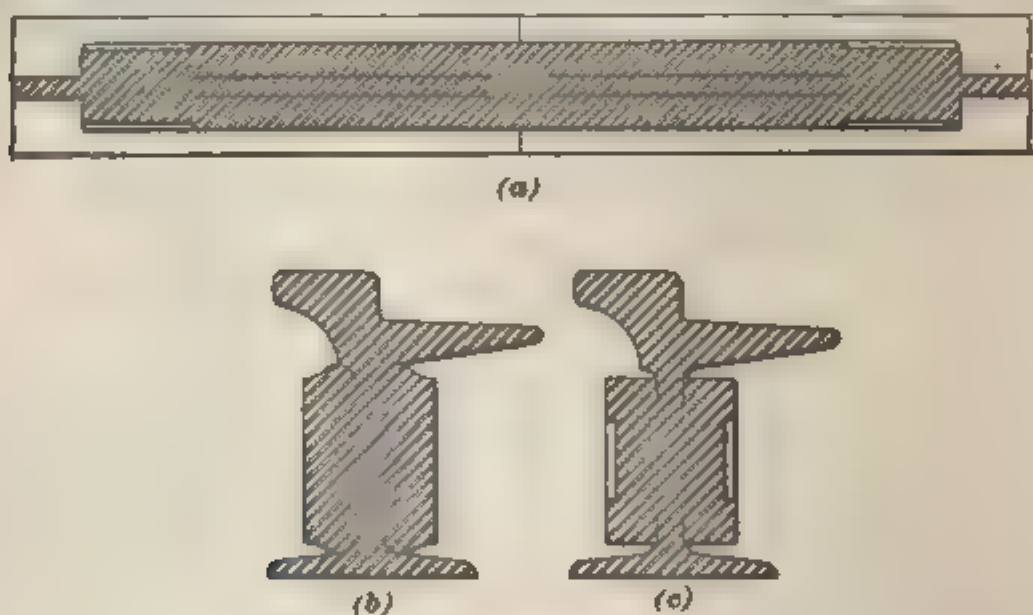



FIG. 10

Fig. 10 (*a*) shows a horizontal section of a completed joint; (*b*) and (*c*) show vertical sections, (*b*) being a section of the center weld and (*c*) of an end weld.

The current supplied to the primary of the transformer is stepped down to a pressure of about 7 volts. The secondary current used for a weld is about 25,000 amperes. The secondary voltage, however, drops somewhat when this large current is flowing so that the power actually taken from the line is not as great as $25{,}000 \times 7 = 175$ kilowatts. As a general rule, about 125 kilowatts for $2\frac{1}{2}$ minutes is sufficient for welding an ordinary joint. On the average, about 80 joints can be made in 24 hours; as a continuous process, working day and night, it takes from 13 to 15 minutes per joint.

**8.** Numerous tests show that an electrically welded joint of this construction has a resistance less than that of a corresponding length of rail. Table I shows the results of some tests made by the General Electric Company. The rails were a standard 6-inch girder type, about 6.7 square inches in area, and splice bars similar to those just described were used.

TABLE I

RESISTANCE OF ELECTRICALLY WELDED RAIL JOINTS

| Joint Number | Resistance Over Joint Ohms | Resistance Over Equal Length of Rail Ohms | Per Cent. Conductivity of Joint Compared With Solid Rail |
|---|---|---|---|
| 1 | .00001675 | .0000279 | 166.29 |
| 2 | .00001625 | .00002636 | 162.2 |
| 3 | .0000182 | .00002785 | 156 |
| 4 | .0000168 | .00002292 | 136.26 |
| 5 | .00001559 | .0000233 | 144 |
| 6 | .00001602 | .0000278 | 177 |
| 7 | .00001457 | .0000238 | 159 |
| 8 | .0000196 | .0000266 | 125 |

The electrically welded joint is very strong, and rails seldom pull apart at the point of welding. Also, the head of the rail is not made hot enough to soften it, and the splice bars do not interfere with the paving.

**9. Thermit Joint.**—A method of making solid rail joints that has recently come into use is the **thermit process**, invented by Dr. Hans Goldschmidt. It has shown remarkably good results and gives a joint equal to the rail in conductivity. Careful measurements have shown that the wear at the joints after a year's service does not exceed, appreciably, the wear on the rail.

**Thermit** is a mixture of finely divided iron oxide and aluminum. The metal aluminum has a great affinity for oxygen, and if this mixture is given a local initial heating

by so-called "ignition powder," a very rapid chemical reaction takes place throughout the whole mixture, and a large amount of heat is liberated. The iron oxide gives up its oxygen to the aluminum and aluminum oxide is formed; at the same time the iron oxide is reduced to pure iron. The heat produced by the reaction is so intense that the mass of molten iron has a temperature of about 3,000° C., and if poured around a rail joint a perfect weld will result.

The appliances required for making a joint by this process are very simple and easily moved from place to place; the cost per joint is practically the same whether a few or many are made, and in this respect the process possesses an advantage over cast welding and electric welding, which are practically out of the question if only a few joints are to be made.

FIG. 11

**10.** Fig. 11 shows a rail joint made with thermit, and Fig. 12 shows the molds that are clamped on either side of the rail to receive the melted metal. These vary in form according to the shape of the rail section, and are made by placing a sheet-iron case (*b*) over a model, or pattern, of the joint

(*a*) (*b*) (*c*)

FIG. 12

and tamping it full of a mixture of china clay and loam; (*a*) and (*c*) show the molds for the two sides of a rail. The edges of the mold are smeared with clay, so as to form a

tight joint, and the halves are then clamped into position, the ends of the rails being first carefully lined up. The thermit compound is placed in a cone-shaped crucible mounted on a tripod directly over the mold; from 15 to 20 pounds is used for each joint, depending on the size of the rail. The crucible is made of an iron case lined with magnesia, and the bottom is formed of a hard magnesia stone provided with a renewable outlet that will stand from nine to ten runs. The hole in the outlet is stopped by a plug. Dirt on the rail ends is cleaned off by means of a scratch brush, and it is not necessary to use a sand blast. A small amount of ignition powder is placed on top of the thermit and lighted by means of a match; in a few seconds the chemical reaction is over and the lower part of the crucible contains a mass of liquid steel at very high temperature, while the slag (aluminum oxide or corundum) floats on top. The crucible is then tapped by knocking the plug in the bottom upwards and the steel runs into the mold in a ½-inch stream. The weight of steel obtained from the reaction is one-half the weight of the thermit mixture. The mold is made so that the metal strikes the under part of the rail first and works its way up to the top, thus carrying up any dirt or slag that may be present. The steel is so extremely hot that it alloys instantly with the ends of the rail and substances, such as manganese or silicon, are generally incorporated in the thermit mixture, so that the steel has approximately the same composition as the rail. After a few seconds, the metal becomes solid and the molds may be removed.

**11. Zinc Joint.**—This joint, Fig. 13, is used on a large scale in Philadelphia, and is the invention of Messrs. C. B. Voynow and H. B. Nichols. The channel plates *a*, *a* are similar in their general shape to those used for the continuous rail joint, Fig. 2, except that there is a space left around the foot of the rail and between the upper flanges of the channel plates and the under side of the tram and head of the rail. The rail ends and plates are cleaned with a sand blast, after which the latter are bolted in position by two temporary

bolts and the holes reamed to a uniform size of $1\frac{1}{32}$ inches by means of a portable pneumatic reamer. The plates are then fastened by twelve 1-inch steel rivets driven by a pneumatic riveter. The riveting process expands the rivets so that the holes are filled tightly. Clamps are then put in position to hold asbestos cloth pads that cover the bottom and ends of the plate; the spaces between the head and tram and plates are calked temporarily with asbestos cloth. The whole joint is then heated by means of portable fuel-oil burners until the temperature is raised to 300° or 400° F., after which molten zinc is poured through a 1-inch hole located in the center of the foot of the plate; space *b* is

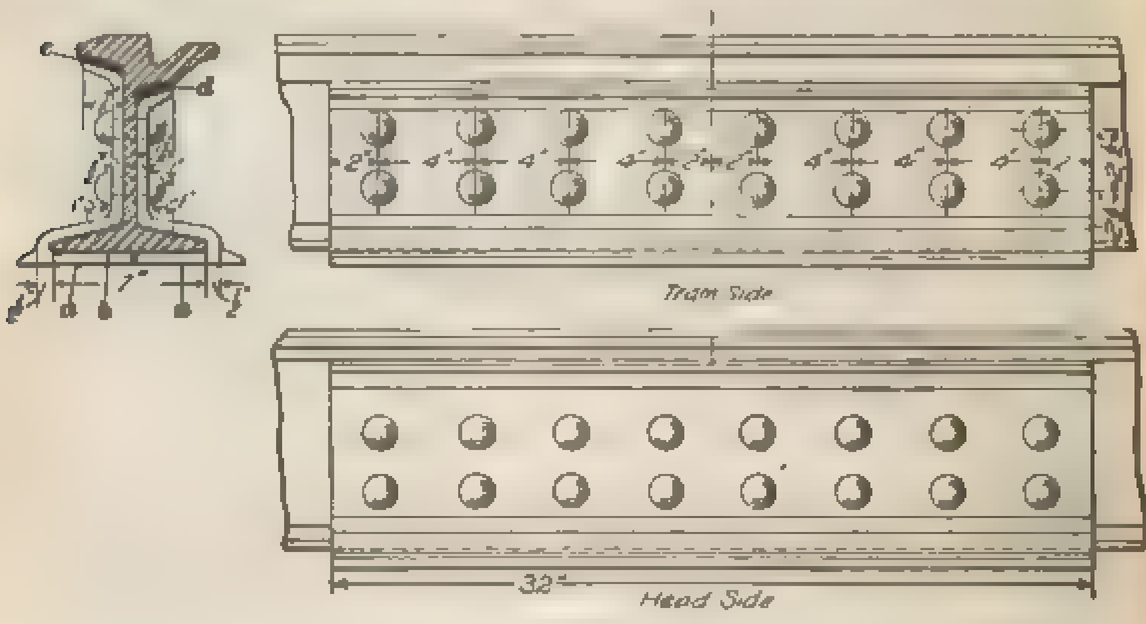



FIG. 13

thus filled with zinc. Dams made of castings padded with asbestos cloth are then arranged around the top of the rail, and spaces *c*, *d* also filled with zinc. This makes a very rigid joint, which allows none of the slight rubbing action that occurs in all bolted fish-plate joints and which sooner or later loosens them. Since the iron surfaces are first thoroughly heated, the zinc attaches itself to the clean iron surfaces, which become galvanized, thus forming a very good electrical contact. Tests have shown that the resistance, after 2 years of continuous use under heavy traffic, is less than that of an equal length of rail. From $22\frac{1}{2}$ to 26 pounds of zinc is required for a joint similar to that shown in Fig. 13.

Outside of the cost of the zinc and the labor of preparing the joint and pouring the metal, the cost of this joint is little more than that of an ordinary one with bolted channel plates.

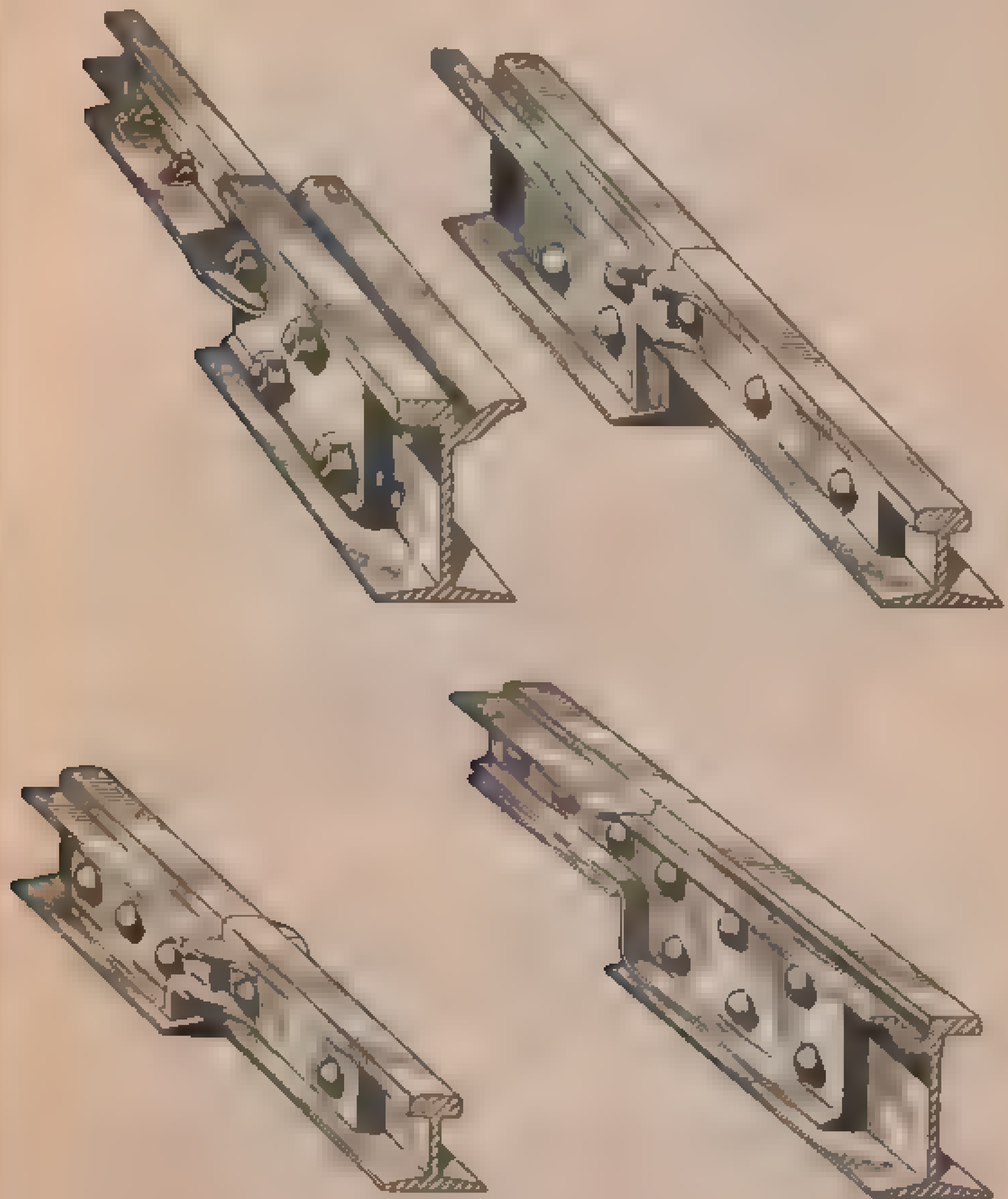


FIG. 14

**12. Combination Joints.**—Where a rail of one section is to be joined to another of different section, a **combination joint** is used; these can be made by using either special splice bars or by means of a section of special rail in the form of a steel casting. Fig. 14 shows four combination

joints where T rails are [illegible] splice bars may be [illegible].

Fig. 15 shows three [illegible] steel. These can be [illegible] joined to the other rails by means of standard joints. This

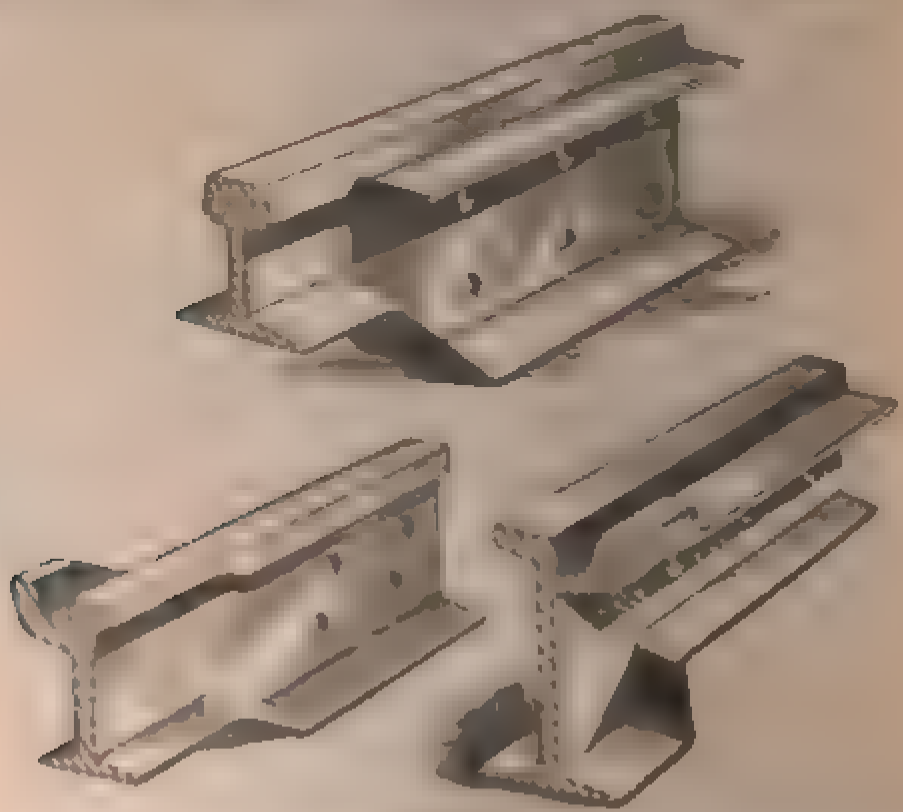


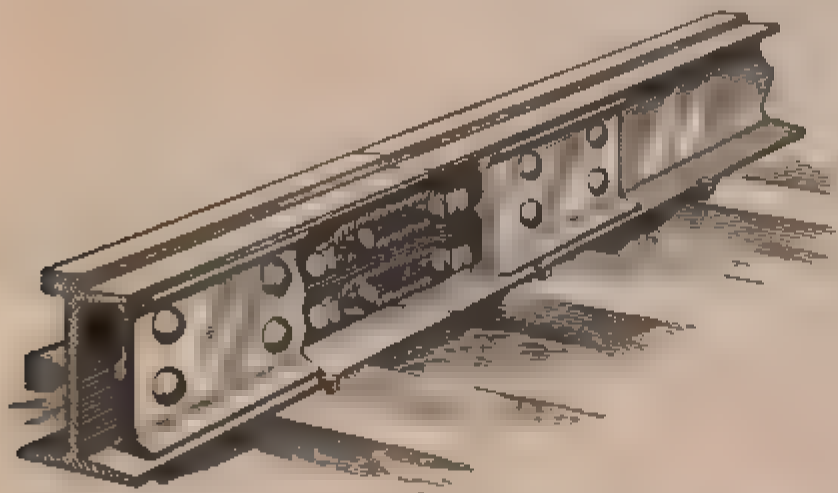
Fig. 15

makes a much better and more substantial construction in every way than the joints shown in Fig. 14 and [illegible] rails are now used in preference to the older construction in the best grades of trackwork.

## RAIL BONDS

**13.** When tracks are not surrounded by paving or when any of the various types of solid joint are not considered practicable on account of cost, the ordinary fish plates must be supplemented by connections, or **rail bonds**, that will carry the current from rail to rail. The fish-plates cannot be depended on to carry the current because they soon become loose or rusty and offer a high resistance. A great many styles of rail bond are in use, so that it will be possible to describe here only a few typical examples. No matter what

type is used, it must always be remembered that if a joint is mechanically poor, the continual movement and pounding



(a)

(b)

(c)

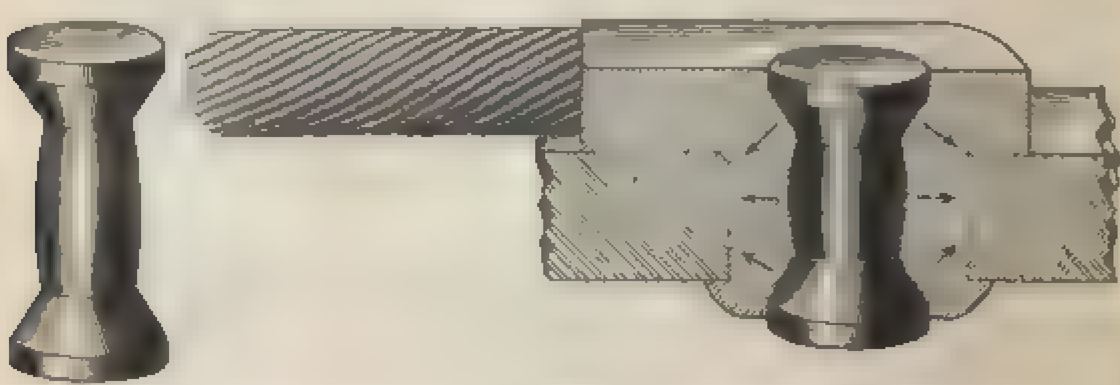
FIG. 16

will sooner or later decrease the efficiency of the bond. It is highly important therefore that the joints be kept in good condition.

If a track is poorly bonded, there will be a continual loss of power due to the resistance at the joints. Low voltage caused by this excessive loss will have its effect on the car equipments, because in order to maintain the schedules the motors will have to be forced and the current per car will be increased. In some cases it may not be possible to maintain the schedules, thus causing a loss of business. Also, if the return circuit is poor, current will come back through neighboring pipes, and trouble on account of electrolysis will result, as described later.

**14.** Rail bonds may, for convenience, be divided into two general classes—*protected* and *unprotected*. **Protected bonds** are so called because they are placed in the space between the channel plate and rail, as shown in Fig. 16 (*a*); **unprotected bonds** either span the fish-plate, as shown in (*b*), or are fastened to the under side of the rail, as in (*c*), in case there is nothing to interfere with the bond projecting on the under side.

**15.** Bonds of the protected type are used in cases where there is sufficient space for them between the fish-plate and rail, but with T rails the space is often not large enough. They may be made considerably shorter than the unprotected type and they do not offer much inducement to copper



(a) (b)
Fig. 17

thieves; on the other hand, short bonds less than 6 inches in length are liable to give trouble from breakage. The bonds shown in Fig. 16 (*a*) and (*b*) are of the General Electric type, made by casting copper terminals on a stranded copper conductor. The copper is cast around

an iron plug of the form shown in Fig. 17 (*a*), and after the terminal has been fitted in the web of the rail the plug is compressed to the form shown in (*b*), thus forcing the metal out against the wall of the hole, as indicated by the arrows, and providing a very firm contact between the terminal and rail. The bond, Fig. 16 (*c*), is made of thin copper strips soldered together at the ends so as to form solid terminals, which are attached to the rail by soldering. It has been found in some cases that soldered bonds deteriorate when they are in contact with damp earth.

**16.** Fig. 18 shows a protected bond of the *double-loop type* shaped so as to give flexibility and at the same time allow openings for the track bolts. It is made of thin copper strips on which copper terminals have been cast. After the terminals *a*, *b* have been passed through the holes in the rail, they are compressed by a special screw compressor that forces the metal out sidewise.

Fig. 19 shows the construction of an *all-wire rail bond* that is made up of copper cable cut to length; the ends are then cold pressed as shown, and afterwards brought to a welding heat and forged to their final shape.

Fig. 20 shows the method of attaching *crown bonds*. A steel pin is driven into a hole in the terminal lug, thus expanding the metal.

**17. Solid Copper Protected Bonds.**—Very satisfactory results in rail bonding have been obtained by using solid plates pressed firmly against the rail web, the contact surfaces being first thoroughly cleaned and coated with copper-mercury amalgam of about the consistency of putty, which adheres to the surfaces and makes a connection of very low resistance. Fig. 21 shows an *Edison-Brown solid bond*; a copper plate *a*, about 3 in. × $1\frac{1}{2}$ in. × $\frac{1}{8}$ in. (the exact dimensions vary with the style of rail to be bonded) is held tightly against the rail when the fish plates are bolted up. Plate *a* has two depressions and two corresponding bosses on the opposite side, that form the contact surfaces; the plate is covered by a thin steel sheet *b* against which a

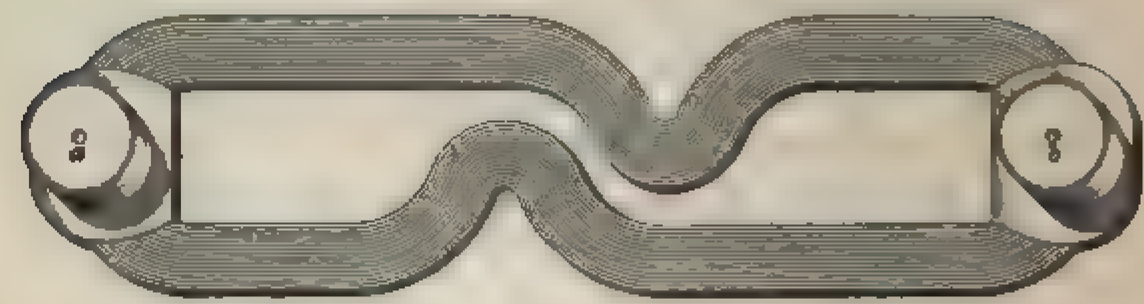


FIG. 18

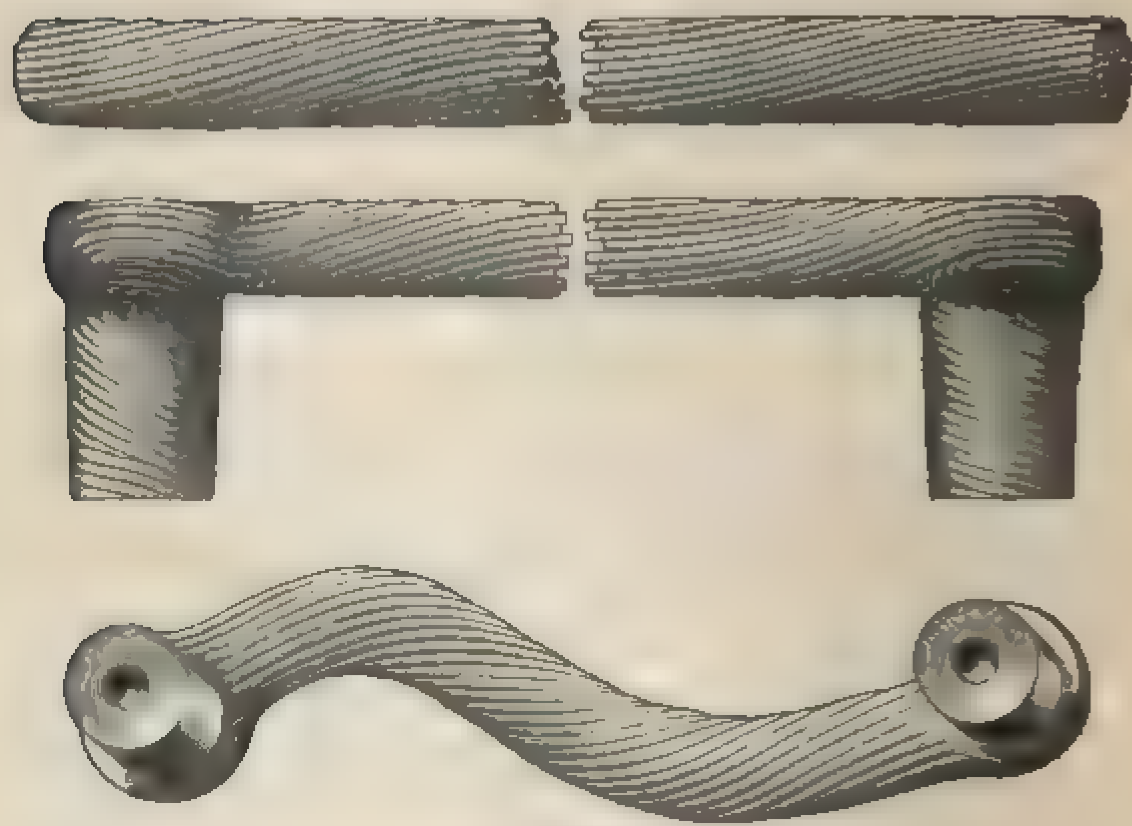


FIG. 19

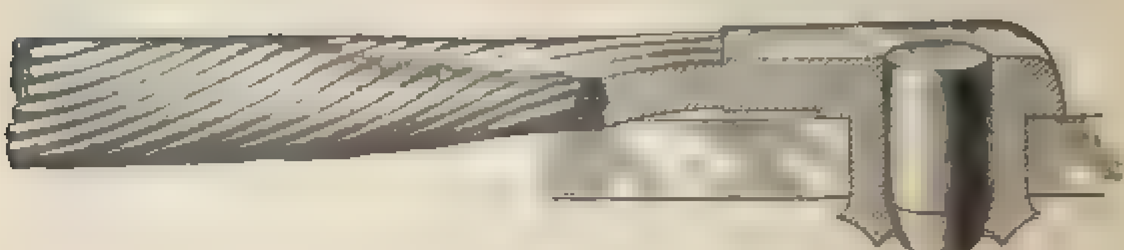


FIG. 20

spring washer *c* bears. The rail is first brightened by means of an emery wheel and the contact surfaces then amalgamated and covered with a thin layer of the alloy. The plate is surrounded by a cork *d*, treated with linseed oil, which, when compressed by the fish-plate, forms a seal around the bond that remains tight even when the fish-plate is loosened considerably. Joints made with amalgam have, after several years of operation, been taken apart and the contact surfaces found to be as bright as when first installed.

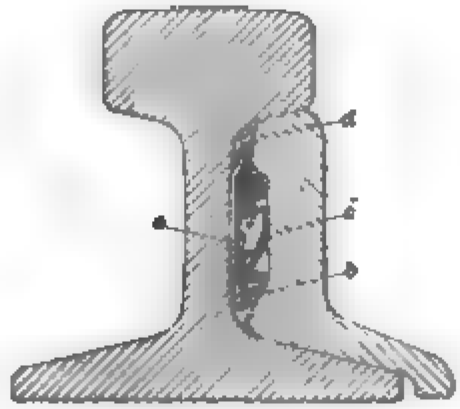


FIG. 21

The *Ajax* solid copper-plate bond, Fig. 22, consists of a piece of copper *a* protected by a steel sheet *b* against which bear cup-pointed setscrews *c*, *c* tapped into plate *d*. The contact surfaces on the rail are

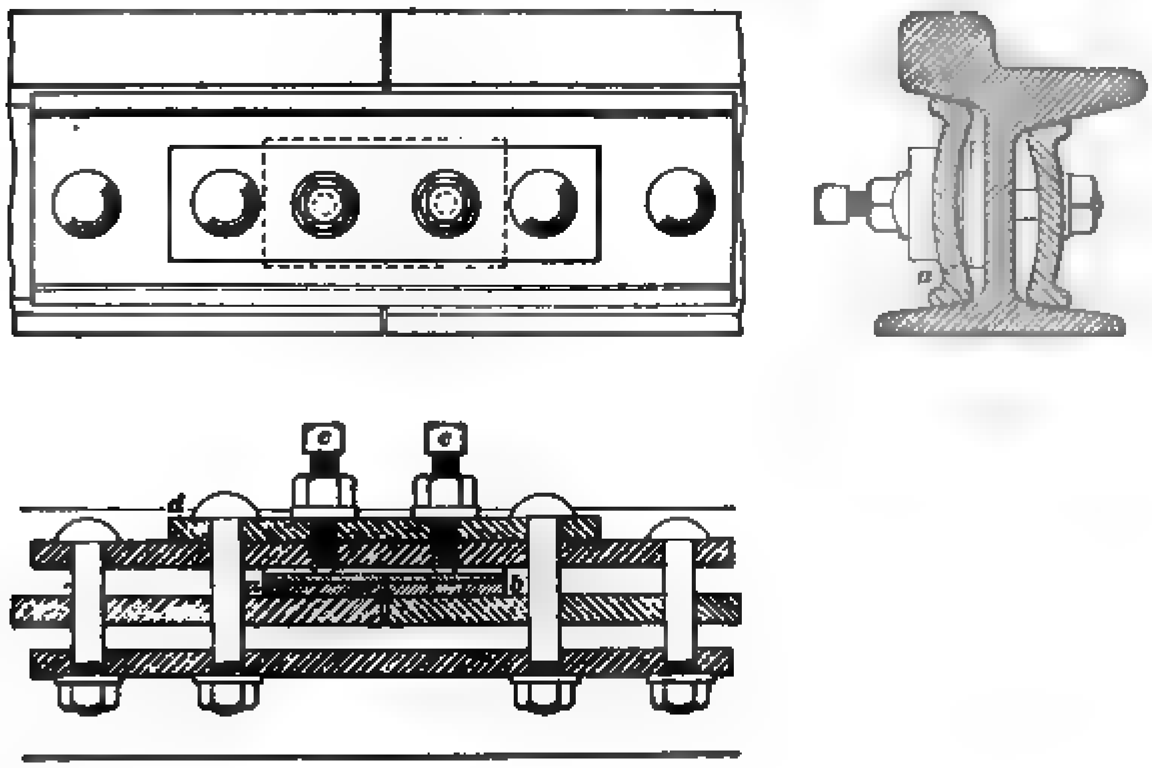


FIG. 22

first ground off and both rail and bond treated with Edison-Brown amalgam.

**18. Plastic Bond.**—Where the fish-plates or channel plates are of large cross-section they can be made to serve as

a bond by providing good contact between the plates and rail. Fig. 23 shows an amalgam bond for this class of work; the plastic amalgam *a* is held in a cork case, which is compressed

(a)

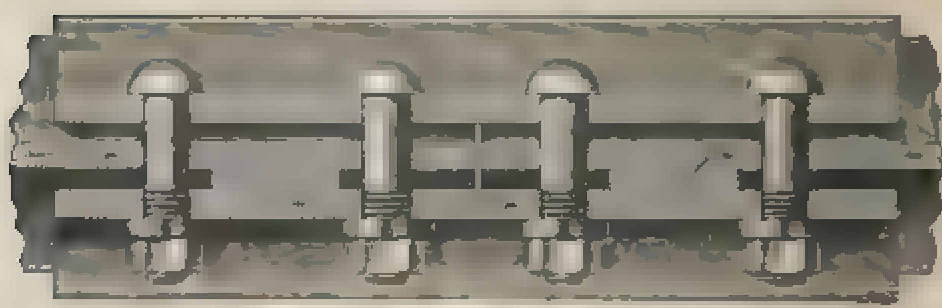


Fig. 23

when the fish plates are bolted together, thus bringing the amalgam into intimate contact with the rail and plate surfaces, which have previously been ground off and amalgamated; the path of the current through the joint is indicated in (*b*). In all of these amalgamated bonds a slight movement between bond and rail does not impair the contact; in fact the amalgam acts, to a certain extent, as a lubricant.

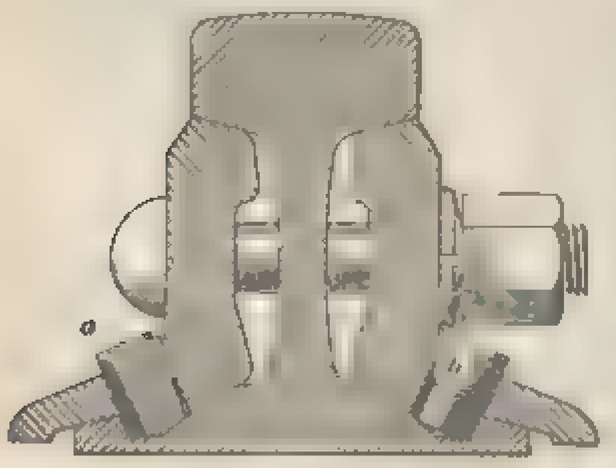


Fig. 24

Fig. 24 shows a method of bonding **T** rails with plastic plug bonds. The fish-plates provide the connection between the abutting rails and electrical contact is made by means of copper plugs *a*, *b*, **T**-shaped in section, that are well

amalgamated and also dip into amalgam placed in the hole. The plugs are afterwards locked in place by burring over with a hammer and blunt chisel. The lower part of the plug is considerably smaller than the hole, so that a certain amount of relative movement between the angle plate and rail can take place with variations in temperature.

**19. Wire Bond With Amalgamated Contacts.** Fig. 25 shows three styles of bond, devised by Mr. W. E.

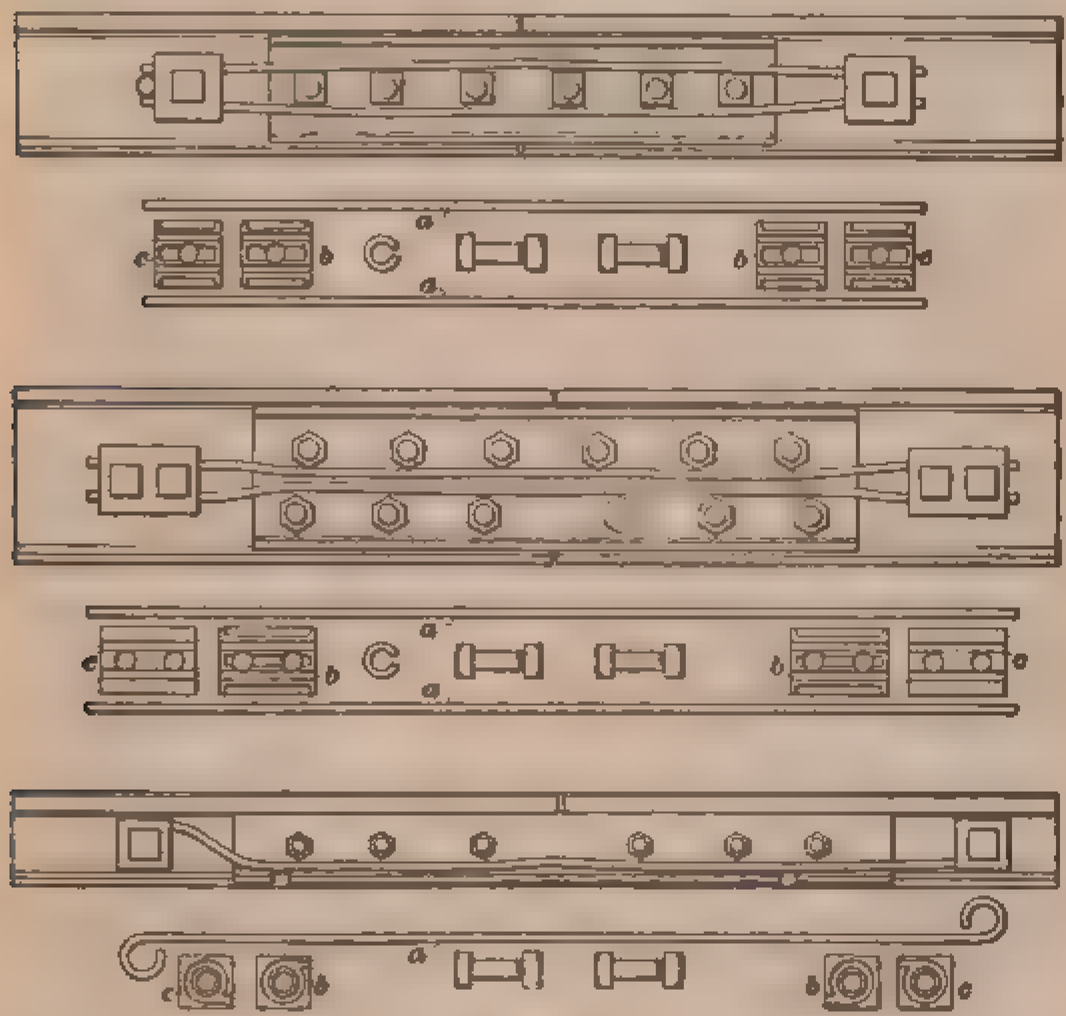



FIG. 25

Harrington, that use ordinary 0000 copper wire for making connection from rail to rail. The wires *a*, *a* are held in contact with the rails by being clamped between two plates *b*, *c* provided with grooves to receive the wires. The contact surface on the web is ground off and covered with plastic amalgam, and an amalgamated cast copper plate is placed against the web of the rail; after the grooves in the casting

and the ends of the wire have been well covered with alloy, a cast-iron plate is placed on top and the whole drawn up tightly by a 1-inch bolt provided with a spring lock washer. Bonds of this type are easily applied; the contacts do not deteriorate, and tests have shown that the resistance across the joint is no greater than that of a corresponding length of rail, provided the bonds are properly proportioned with regard to the rail section.

**20. Resistance of Bonds.**—In making track joints, the aim should be to keep the electrical resistance at least as low as the resistance of a corresponding length of rail. It is not difficult to do this with a new joint, but the constant jarring and slight movements to which the bonds are subjected will often cause a great increase in resistance. Poor connections from rail to rail are just as detrimental as poor joints in the overhead feeders and much more attention is now paid to efficient rail bonding than formerly.

**21.** A No. 0000 B. & S. wire has a cross-section of .1662 square inch which, assuming the resistance of steel as 10 times that of copper, is equivalent to 1.662 square inches of steel. A bond 1 foot long connecting two 60-pound rails (6 square inches cross-section) will have a resistance equal to that of $\frac{6}{1.662} = 3.61$ feet of rail, neglecting resistance at the bond contacts. The total resistance of a joint is the resistance of the bond in parallel with the resistance that the joint would have without any bond. The channel plates or fish-plates provide some conductivity, but it is very uncertain owing to the variable nature of the contacts between plates and rail. If the work is done carefully, the resistance as measured across the fish-plates and bond, say 3 feet of rail, can be kept as low as the resistance of 3 feet of solid rail. It is necessary, of course, to proportion the bonding according to the weight of the rail; for example, a 90-pound rail should be bonded heavier than a 60-pound, either by using a heavier bond connection or, preferably, by providing two or more bonds at each joint.

## TABLE II

### LENGTHS OF RAIL EQUAL IN RESISTANCE TO BOND 1 FOOT LONG

| Weight of Rail Pounds per Yard | Cross-Section Square Inches | Equivalent Cross-Section of Copper Square Inches | Feet of Rail Equal in Resistance to Bond 1 Foot Long Assuming Resistance of Steel = 10 × Resistance of Copper | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Single No. 0000 B. & S. | Two No. 0000 B. & S. in Parallel | Single No. 000 B. & S. | Two No. 000 B. & S. in Parallel | Single No. 00 B. & S. | Two No. 00 B. & S. in Parallel | Single No. 0 B. & S. | Two No. 0 B. & S. in Parallel |
| 40 | 4 | .4 | 2.41 | 1.21 | 3.04 | 1.52 | 3.82 | 1.91 | 4.82 | 2.41 |
| 45 | 4.5 | .45 | 2.71 | 1.36 | 3.41 | 1.71 | 4.31 | 2.16 | 5.42 | 2.71 |
| 50 | 5 | .5 | 3.01 | 1.51 | 3.79 | 1.89 | 4.78 | 2.39 | 6.03 | 3.02 |
| 55 | 5.5 | .55 | 3.31 | 1.66 | 4.17 | 2.09 | 5.26 | 2.63 | 6.63 | 3.32 |
| 60 | 6 | .6 | 3.61 | 1.81 | 4.55 | 2.28 | 5.74 | 2.87 | 7.24 | 3.62 |
| 65 | 6.5 | .65 | 3.91 | 1.96 | 4.93 | 2.47 | 6.22 | 3.11 | 7.84 | 3.92 |
| 70 | 7 | .7 | 4.21 | 2.11 | 5.31 | 2.66 | 6.70 | 3.35 | 8.44 | 4.22 |
| 75 | 7.5 | .75 | 4.51 | 2.26 | 5.69 | 2.85 | 7.18 | 3.59 | 9.04 | 4.52 |
| 80 | 8 | .8 | 4.81 | 2.41 | 6.07 | 3.04 | 7.65 | 3.83 | 9.65 | 4.83 |
| 85 | 8.5 | .85 | 5.11 | 2.56 | 6.45 | 3.23 | 8.13 | 4.07 | 10.25 | 5.13 |
| 90 | 9 | .9 | 5.41 | 2.71 | 6.82 | 3.41 | 8.61 | 4.31 | 10.85 | 5.43 |
| 95 | 9.5 | .95 | 5.71 | 2.86 | 7.21 | 3.61 | 9.09 | 4.55 | 11.46 | 5.73 |
| 100 | 10 | 1.00 | 6.01 | 3.01 | 7.59 | 3.79 | 9.57 | 4.79 | 12.06 | 6.03 |
| 105 | 10.5 | 1.05 | 6.31 | 3.16 | 7.96 | 3.98 | 10.05 | 5.03 | 12.66 | 6.33 |
| 110 | 11 | 1.10 | 6.61 | 3.31 | 8.34 | 4.17 | 10.52 | 5.26 | 13.27 | 6.64 |
| 115 | 11.5 | 1.15 | 6.91 | 3.46 | 8.73 | 4.37 | 11.01 | 5.51 | 13.87 | 6.94 |

**22.** Table II shows the lengths of rail that are equal in resistance to bonds of various sizes 1 foot long. Thus, if a 70-pound rail is bonded with two No. 0000 bonds, each 1 foot long, the resistance of the bonds is equal to that of 2.11 feet of rail, assuming that the resistance between bonds and rail is negligible and that steel has a resistance 10 times that of copper.

**23.** The cost of bonds for a given piece of track is such a small item, compared with the total cost, that it pays to be liberal when installing them. Table III shows the resistance of a number of types of bond as measured by Mr. W. E. Harrington. These tests show that it is advisable to use amalgam on bond contacts even with those types of bond that were originally designed for use without amalgam.

**24. Cross-Bonding.**—It is necessary to cross-bond the rails at certain intervals so that a break in one or more joints may not seriously impair the conductivity of the return circuit. For example, consider a single-track road where the two rails are bonded throughout but not connected to each other. If a break occurs at a given joint, the portion beyond the joint is of no use in aiding as a return for the current and an additional load is thrown on the other rail. If, however, the rails are cross-connected at intervals, the current can flow around the break and only a small section of the rail is cut out. On double-track roads all four rails should be connected together. Cross-bonding, with No. 0000 copper, should be provided at least every 500 feet; tinned wire is very commonly used for this purpose. For similar reasons, the current should be carried around all switches, frogs, and special work by means of heavy bond wires (250,000- or 500,000-circular-mil cable). Joints in special work are liable to work loose because of the pounding, and it pays to take extra precautions in the bonding at all such points on the road.

**25. Return Feeders.**—It is usually necessary to connect the track to the negative bus-bar in the power house by

## TABLE III

### RESISTANCE OF RAIL BONDS

| No. | Kind of Rail | Kind of Bond | Distance Center to Center of Bond Contacts Inches | Length of Bond Inches | Size of Contact | Size of Bond B. & S. | Number of Wires | Resistance Ohms |
|---|---|---|---|---|---|---|---|---|
| 1 | 7-inch girder, Pennsylvania Steel Co. Sec. No. 238 | Iron channel pin | 45 | 48 | $\frac{9}{16}$-in. pin | 0 | 1 | .00071 |
| 2 | | Crown | 30 | 36 | $\frac{7}{8}$-in. head | 0000 | 1 | .000247 |
| 3 | | Crown (amalgamated) | 30 | 36 | $\frac{7}{8}$-in. head | 0000 | 1 | .000185 |
| 4 | | Columbia | 30 | 36 | $\frac{7}{8}$-in. head | 0000 | 1 | .000131 |
| 5 | | Columbia (amalgamated) | 30 | 36 | $\frac{7}{8}$-in. head | 0000 | 1 | .000126 |
| 6 | | Stranded crown | 5 | 7 | $\frac{7}{8}$-in. head | 0000 | 1 | .0001 |
| 7 | | Plastic socket | $3\frac{1}{2}$ | | | | | .000093 |
| 8 | | Ajax bond | | $8\frac{1}{2}$ | $8\frac{1}{2}$-sq. in. | $\frac{1}{4}$-sq. in. section | | .000041 |
| 9 | | Solid rail (no joint) | 24 | | | | | .000024 |
| 10 | | Joint only (no bond) | 24 | | | | | .00071 |
| 11 | 60-lb. T | Ajax (double) | 30 | | | | | .00004 |
| 12 | 60-lb. T | Solid rail (no joint) | 30 | | | | | .000035 |
| 13 | 9-in. girder | Ajax | 24 | $5\frac{3}{4}$ | $5\frac{3}{4}$-sq. in. | $\frac{3}{8}$-sq. in. section | | .000031 |
| 14 | | Solid rail | 24 | | | | | .00002 |

means of a number of return feeders; these are very often attached to the rails by bond connections similar to regular rail bonds.

Fig. 26 shows a return feeder attached by means of a cast-iron terminal and plastic bond; terminal *a* holds the cork case against the web, forming a receptacle into which are

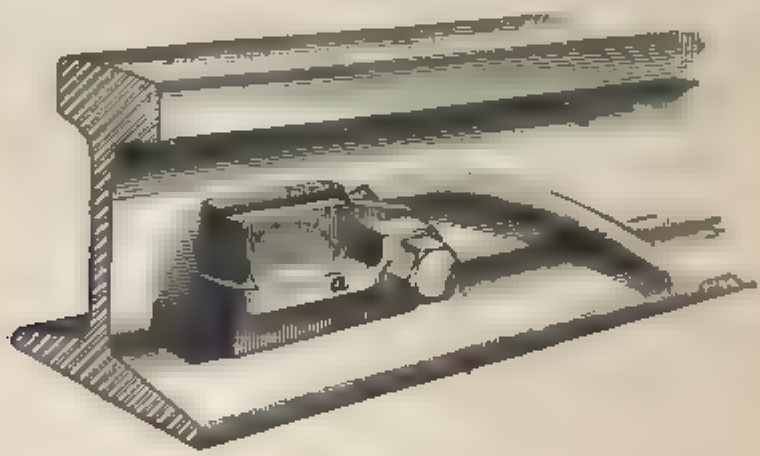



FIG. 26

placed the end of the wire and some of the plastic alloy. The cable end and the spot on the rail are also amalgamated and the casting is bolted to the rail by a $\frac{3}{4}$-inch bolt that is afterwards riveted over to prevent loosening. Similar terminals are used for loops around special work. Fig. 27 shows an electrically welded or brazed feeder cable connection; a copper block *a* about 4 inches square and $1\frac{1}{2}$ inches thick is provided with a groove on one face to take the cable when the block is placed against the rail, as shown. A steel plate *b* is placed over the block, and the cable and blocks brazed to the rail by means of the electric welder. Hard spelter is used, and by this means a 500,000-circular-mil cable can be attached to the rail so that the carrying capacity at the contact is fully as good as that of the cable.

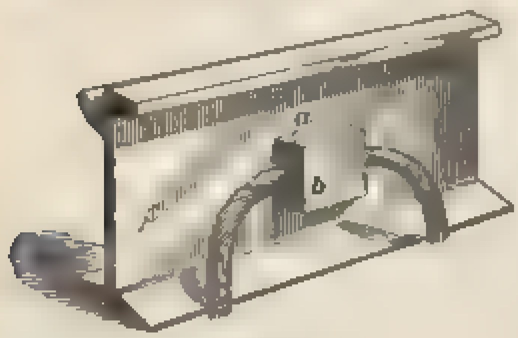



FIG. 27

At one time, it was customary to run a ground conductor parallel to the rails and tap it to them at frequent intervals in order to improve the conductivity of the return circuit. If

the rails are properly bonded so as to take full advantage of their conductivity there is no need of such an auxiliary wire and its use has been practically abandoned; the money may be used to better advantage in improving the rail bonding.

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## BOND TESTING

**26.** No matter how well a track may be bonded, tests should be made frequently to see that the bonds are in good condition. This is especially necessary around railroad crossings, special work, or wherever low joints are noticed. It is not necessary to measure the actual resistance of each joint; comparative readings are all that is required. For a given class of bonding, the resistance of a joint in good condition as compared with a certain length of rail is known, and it is only necessary to measure the resistance of the joint in terms of rail length; any joints showing an abnormally high resistance can then be investigated. Usually 3 feet of rail is taken as the standard and the resistance, measured between two points 18 inches on either side of the joint, is compared with that of 3 feet of rail. For example, the bonding may be such that a joint in good condition has a resistance perhaps slightly over that of 3 feet of rail, and if a test showed that the resistance were over twice that of the standard rail length, the bonding would be considered poor.

**27. Drop-of-Potential Test.**—The simplest method of testing for poor bonds is by measuring the drop across the joint by means of a millivoltmeter and comparing this with the drop across 3 feet of rail. Fig. 28 shows a method of doing this very rapidly and accurately by means of a test car especially fitted up for the purpose. A wooden beam *a* is suspended underneath the rear car platform so that it will be a few inches above the rail. A spring is arranged to press down on the beam and means are also provided for raising it when not in use. To the under side of the beam are attached two stiff copper brushes *b*, *b'*; these are made of several leaves of sheet copper and are set on a slant, as shown, so that they will slide easily along the rail and make

a good running contact. They should have at least 1 square inch contact surface with the rail; high-contact resistance will have a marked effect on the accuracy of the millivoltmeter readings. A resistance $c$ is carried on the car so that a large steady current can be made to flow through the track; resistance wire wound on a frame and submerged in a barrel of water is capable of carrying a large current and furnishes a resistance that is fairly constant.

In making bond tests, it is best to pass sufficient current through the joints to give good readable deflections on the millivoltmeter and the current used to propel the test car, or that taken by other cars on the line, is not usually large

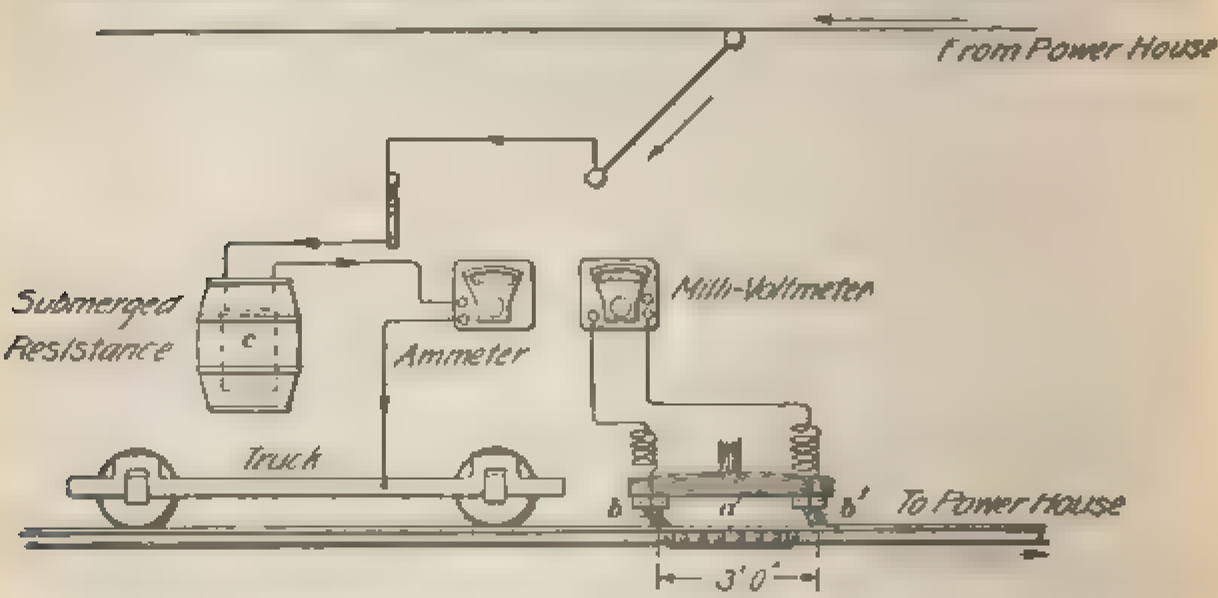


FIG. 28

enough or steady enough for the purpose. The current flows from the trolley, through the resistance and ammeter to the truck and rails, and thence back through the track to the power house. The brushes $b$, $b'$ are placed 3 feet apart, and as the car moves slowly over the track the brushes span the joints in succession. A millivoltmeter is connected to the brushes, and when the brushes are as shown in Fig. 28 it indicates the drop across the joint. When the brushes are not on a joint, the voltmeter reading is the drop across 3 feet of solid rail. Since the current in the rail is the same as that in the joint, the voltmeter readings are proportional to the resistances of 3 feet of rail and 3 feet including the joint. The car can also be fitted with another set of brushes

over the other rail, this set being connected to a second voltmeter; tests of the bonds on both sides of the track can thus be made at the same time. The rheostat is adjusted so that a normal joint will give a good readable deflection and the car is then run slowly over the line, any joints that give abnormally high readings can thus be quickly located, marked by ejecting whitewash on the track, and afterwards examined.

FIG. 29

The test should preferably be carried out at some time when traffic is light so as not to interfere with the regular operation of the cars.

**28. Conant Bond Tester.** The method of testing devised by Mr. R. W. Conant, while it is not as rapid as the one just described, is very useful where a moderate number of joints are to be gone over. Fig. 29 shows the method of using the instrument. A T-shaped pole is provided with three hardened-steel knife-edge contacts $a$, $b$, $c$, and

when the pole is placed on the rail as shown, contacts *b*, *c* span the rail joint and *a*, *b* span 3 feet of solid rail, plate *p* being placed over the joint. The pole is made of tough wood that has considerable spring to it and when the two end contacts rest on the rail, the center contact is 1 or 2 inches above the rail and is pressed down by placing a foot on the pole, as shown; this forces the end contacts out sidewise slightly and the hardened chisel-like contacts cut through any scale or dirt that may be on the rail, thus making a good connection. In order to make sure that the contact is good, the center pole can be moved back and forth, as indicated by the dotted lines; the contacts must be sharpened occasionally by means of a small oilstone.

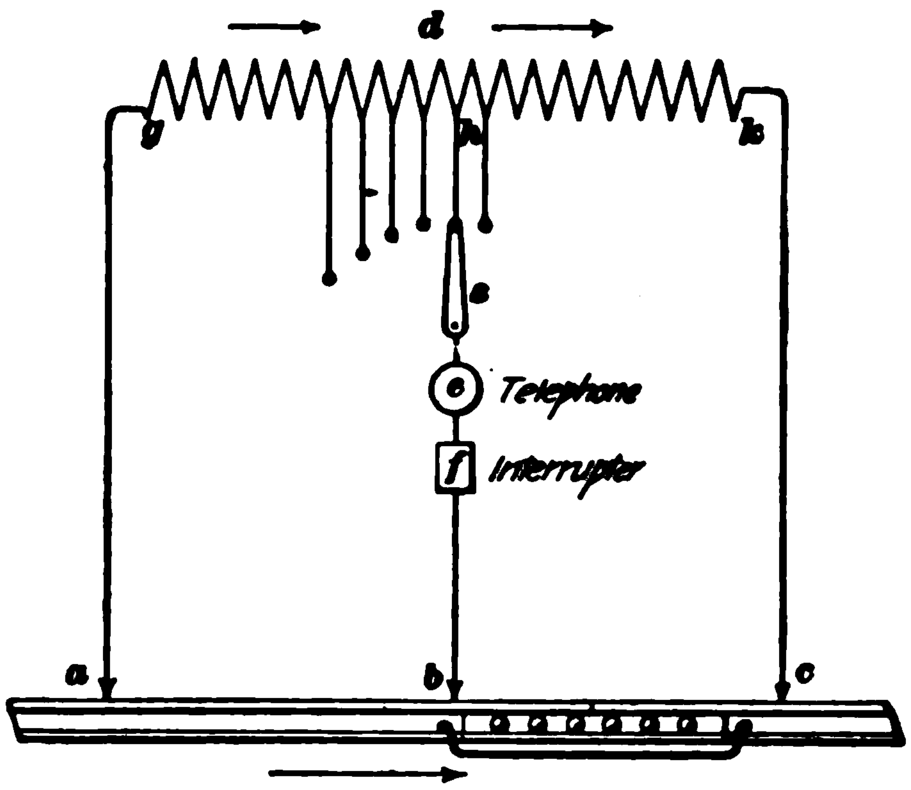

FIG. 30

**29.** The operation of the instrument will be understood from Fig. 30, where *a*, *b*, *c* represent the three contacts on the rail; *d* is a resistance to which the central contact can be connected at various points by means of a multipoint switch *s*. In series with the middle wire is included a telephone receiver *e* and an interrupter *f* consisting of a clockwork mechanism that drives a toothed contact wheel on which presses a small contact spring. The instrument works on the principle of a Wheatstone bridge and is operated by current obtained from the rail.

Assume that the rail current is represented by the heavy arrow; it will be the same in the section of rail *a b* and in the joint *b c* and will fluctuate according to the number of cars in operation beyond the joint. Resistance *d* being shunted across the rail and joint, part of the current will

flow as shown by the small arrows. If the rail section $a\,b$ is equal in resistance to the joint $b\,c$ and if switch $s$ is so placed that resistance $g\,h$ is equal to $h\,k$, there will be no current in the middle wire and no sound in the telephone because points $h$ and $b$ will be at the same potential. If the joint has a greater resistance than the rail section, a balance can be obtained by moving the switch to the left, thus virtually shifting point $h$ along the resistance until the drops through the two resistance sections become equal to the drops through the corresponding rail sections. It is hardly possible to obtain such an exact balance that there will be no sound whatever in the telephone, but the point where the sound is a minimum can be quickly located. The interrupter is used to make a clicking sound in the telephone; fluctuations in the railway current would not in themselves be regular enough to give an easily detected sound.

The contacts of switch $s$ are numbered so as to read off the resistance of the joint in terms of 3-foot length of rail. Thus, if a balance is obtained with the switch on point 1 it indicates that the joint has a resistance equal to 3 feet of rail. If a balance is obtained on 1.5, the joint resistance is equal to $1.5 \times 3$ or 4.5 feet of rail; if a balance is obtained on 2, the joint resistance is equal to 6 feet of rail. Readings from 1 to 2 are considered as indicating good bonding; readings on points 3 or 4 indicate poor bonding; all readings above 4 indicate bad bonding. For any given class of bonding, the point at which the switch should give a balance for a good joint is known, and bad joints can be easily located. Good bonding will never have a resistance greater than twice the same length of rail, and in the better class of work it will not exceed 1 to 1.5 times an equal length of rail; in fact, if proper care is taken there is no reason why the joint resistance should not be less than that of a 3-foot rail length, particularly if solid rail joints are used.

**30.** Table IV shows the results of some tests on different bonds made by the method shown in Fig. 28.* They were

* W. E. Harrington, Journal of the Franklin Institute, Vol. CLVII.

## TABLE IV

### RESULTS OF RAIL-BOND TESTS

| No. | Trade Name of Bond | Trade Name of Rail Section | Line Voltage | Amperes Used | Drop Across 3-Foot Section of Rail (Millivolts) | Drop Across 3-Foot Section Including Bond (Millivolts) | Ratio Resistance of Bond to Rail | Date Placed | Style of Joint |
|---|---|---|---|---|---|---|---|---|---|
| 1 | C & S No. 1 (See Fig 25) | 9-inch girder Pennsylvania Steel Co. Sec 200 | 550 | 200 | 28 | 12 | .43 | 1899 | Regulation fish-plate |
| 2 | C & S No 2 (See Fig 25) | 9-inch girder Pennsylvania Steel Co Sec 200 | 545 | 220 | 27 | 15 | .55 | 1900 | Regulation fish-plate |
| 3 | C. & S No 3 (See Fig 25) | 4½-inch T Pennsylvania Steel Co. Sec 237 | 540 | 150 | 30 | 12 | .40 | 1901 | Regulation fish-plate |
| 4 | Bryan | 7 inch girder Pennsylvania Steel Co. Sec 238 | 550 | 200 | 25 | 14 | .55 | 1900 | Regulation fish-plate |
| 5 | Flexible plug | 4½-inch Wharton | 425 | 140 | 40 | 80 | 2.00 | 1900 | Regulation fish-plate |
| 6 | Crown plug | 6-inch Wharton | 430 | 150 | 24 | 75 | 3.12 | 1896 | Regulation fish-plate |
| 7 | Trenton plug | 6-inch Wharton | 430 | 155 | 25 | 78 | 3.12 | 1898 | Regulation fish-plate |
| 8 | Cast weld | 9-inch girder Pennsylvania Steel Co. Sec 200 | 555 | 200 | 28 | 12 | .43 | 1898 | Cast weld Wharton |
| 9 | Plastic Edison-Brown | 9-inch girder Pennsylvania Steel Co. Sec 200 | 550 | 200 | 27 | 18 | .66 | 1896 | Regulation fish-plate |
| 10 | Flexible U bond | 7-inch girder | 460 | 180 | 28 | 35 | 1.25 | 1899 | Regulation fish-plate |
| 11 | Ajax | 9-inch girder Pennsylvania Steel Co Sec. 200 | 560 | 160 | 29 | 26 | .90 | 1900 | Regulation fish-plate |

made in September, 1903, so that the bonds had been in use for periods ranging from 2 to 7 years.

**31. Testing Resistance of Track-Return Circuit.** After a road has been in operation some time, it is often found that the drop on certain sections is larger than it should be and the question naturally arises as to whether the track return is at fault or whether more copper is required in the overhead feeders. To find this out, it is necessary to know the comparative resistances of the two; if the track resistance is high compared with that of the overhead line, additional return feeders should be run and vice versa.

Fig. 31 shows one method of measuring the resistance of a railway circuit; $FF$ is the feeder running out to the section under consideration and $RR$ the rail return. A time

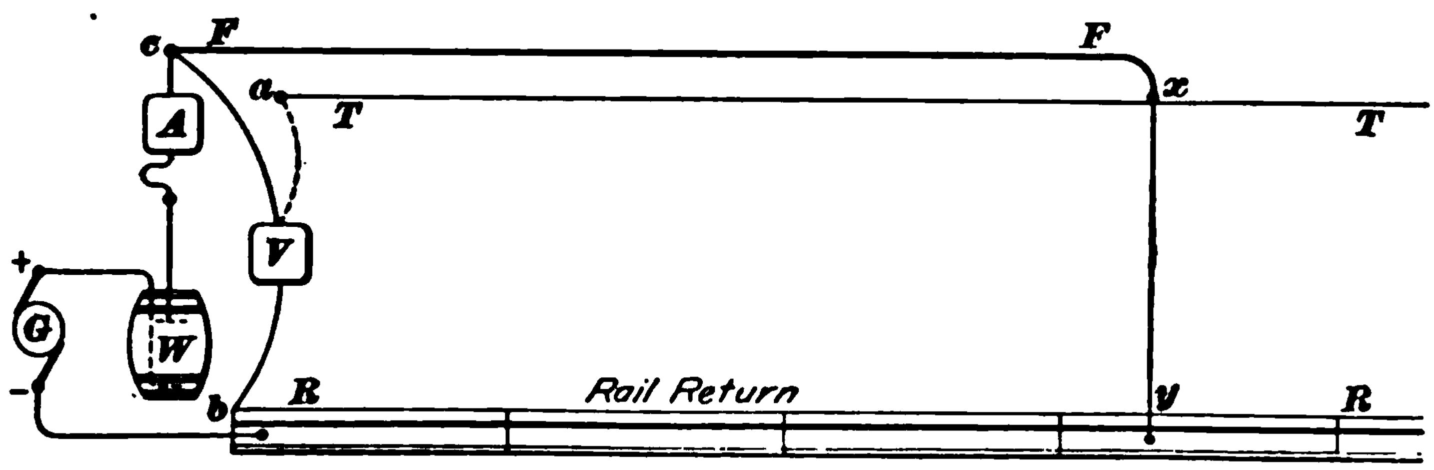


FIG. 31

is selected at night, when traffic can be kept off the section for a short time, and a water rheostat $W$ is connected in series with the feeder $F$ and the regular feeder ammeter $A$. The feeding-in point $x$ is connected to the track as shown at $xy$, and a steady current sent through the circuit $G+-W-A-c-F-F-x-y-R-G-$. The drop through the entire feeder and rail circuit is measured by a voltmeter $V$ connected to $c$ and $b$. From the readings of $A$ and $V$, the total resistance of the feeder and rail circuit is at once determined. The resistance of the feeder $FF$ can be calculated from its known length and cross-section, and its resistance subtracted from the total resistance of the circuit will give the resistance of the track return.

The above method of finding the resistance of the track return assumes that there are no bad joints or unusually poor conductivity in any part of the feeder $FF$, but such is not always the case. If the trolley wire runs back to the power house or if there is another feeder near by that can be used as a pressure wire, the drops in the feeder and track can be measured separately and an accurate idea gained as to just how the drop is distributed. For example, if the upper voltmeter terminal is connected to the end $a$ of the trolley wire instead of to $c$, the reading obtained will be the drop through the track alone, because the voltmeter takes such a small current that there will be practically no drop through $Tx$. If one terminal of the voltmeter is connected to $c$ and the other to $a$, the reading obtained will be the drop in the feeder $FF$. This method is the one to be preferred, because it at once gives an accurate comparison between the loss in the overhead work and the loss in the track and shows what part of the system requires attention in order to bring about better working conditions.

## TRACK CONSTRUCTION

### GENERAL FEATURES

**32.** The kind of track construction to be used for a given road will depend largely on where the road is located, and the allowable cost. If the soil has a very poor bottom, the subwork of the roadbed must be much more substantial than where the soil is firm or where there is a rock bottom. Again, in some places provision must be made for draining the roadbed.

**33. Ties.**—The woods most commonly used for ties are white oak, red oak, cedar, chestnut, yellow pine, hemlock, and spruce; oak is used more than any of the others. Ties for a standard gauge (4 feet 8½ inches) road are usually 6 in. × 8 in. × 8 ft. and are spaced from 2 to 2½ feet between

centers. In some classes of trackwork in paved streets, where the tracks are largely supported by concrete, the spacing of the ties may be much wider than that required for an open track; in fact, in certain classes of construction, ties are dispensed with altogether, the rails being held to gauge by means of tie-rods spaced about 10 feet apart.

The life of a tie depends much on climatic conditions and the material in which it is bedded. Under ordinary conditions, sound oak, cedar, or chestnut ties should last from 8 to 10 years, while pine, hemlock, and spruce will last from 4 to 6 years. Ties, when completely covered, deteriorate much more rapidly than when partly exposed; when they are raised on stone ballast, the drainage is much more perfect than when buried in earth, and the life is much longer.

**34. Arrangement of Joints.**—In placing the rails, opinion is divided as to how the joints should be disposed; some engineers prefer putting the joints opposite each other, while others advocate staggering them, i. e., making the joint in one rail come in line with the center of the opposite rail. It has been the general custom in America to stagger the joints, but the use of opposite joints is now becoming more common, as many engineers are strongly of the opinion that they are much to be preferred to staggered joints. When staggered joints are in bad condition, the car acquires a disagreeable side rolling motion very much like that due to a sprung axle. The car is thrown from one side of the track to the other and the part of the rail opposite a joint becomes worn unevenly, thus making the side motion still worse, with the result that the track is thrown out of alinement. With opposite joints, the worst that can happen is an up-and-down motion, which will jolt the car, but will not cause the severe side thrusts that are always found with defective staggered [illegible]

**35. Metho[illegible]stalling Electric Roadbeds.**—On interurban ele[illegible]m construction can be followed closely. It fre[illegible] however, that electric roads

are run in streets that, if not already paved, will be at some future time, and hence the conditions are somewhat changed. The methods of building electric roads differ so radically that it can be truly said that the only elements of construction in common to all electric roads are the earth and the rails. Some roads have wooden cross-ties, some metal, and others have no cross-ties at all. One road must build an expensive substructure for its roadbed and another, on account of natural conditions, may have to lay scarcely any roadbed. There can be no better way of bringing out these several points in construction than to take examples of roads on which they occur.

## TYPICAL ROADBEDS

### INTERURBAN ROADS

**36.** The permanent character of the track as a whole depends greatly on the character of the roadbed; if, after the substructure is laid, the roadbed gives or swerves in places, everything that rests on it gives and swerves also, so that in course of time the surface of the track becomes undulating and serpentine in outline. Electric interurban roads, as far as possible, now follow steam-road practice in their roadbed and track-work, and for out-of-town work they could not do better.

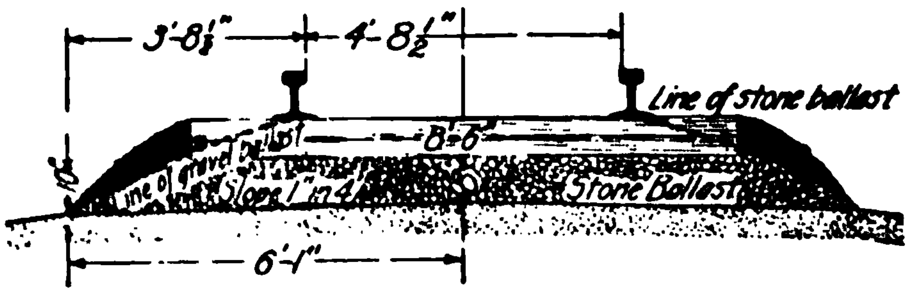

FIG. 32

Fig. 32 shows a standard steam-road construction; other examples of track construction for cross-country roads have already been shown in connection with line work. The same care and exactness that are observed in steam-road construction should be observed in electric railroading, where the train speeds are often almost as high and other conditions just as severe.

## CITY ROADS

**37.** Fig. 33 shows a cross-section of a substantial roadbed in the State of New York. The figure shows a single track only, although the road is double track. A trench 23 inches deep is opened up 18 feet wide and is well rolled and

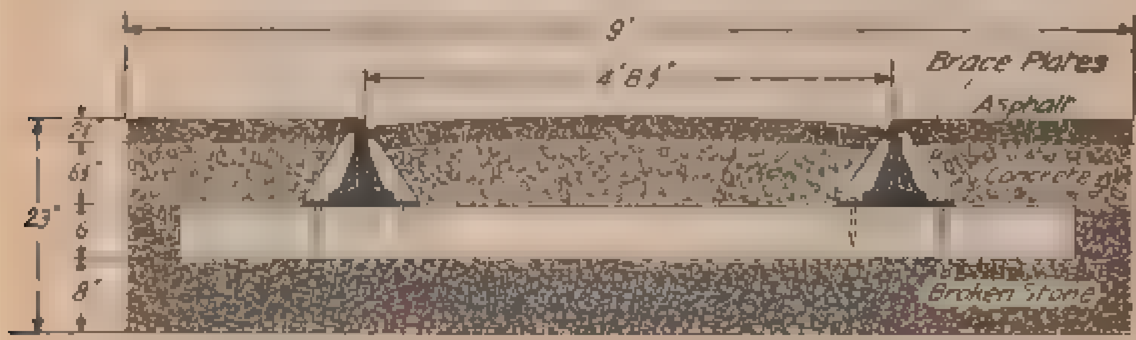


Fig. 33

filled to a depth of 8 inches with 2-inch broken stone, soft spots in the rolled surface being dug out and also filled with stone or other solid material. The stone is rolled until it is firm at a depth of 8 inches. On this ballast are laid the ties 6 in. × 7 in. × 7 ft. 6 in., a little less than 2 feet between centers, except at the joints, which are supported by three ties about 15 inches between centers; 60-foot rails are then laid on the ties, ends butted and joints staggered; before jointing, the ends of the rails and the joint plates are well cleaned to take the bonds. The rails are then coupled, the plates bolted tight, brace plates installed every 3 or 4 feet, ties lined up and spiked to the rail. The track is then lined and surfaced and the space between the ties filled with broken stone, well tamped to the top of the tie The rail is then finally

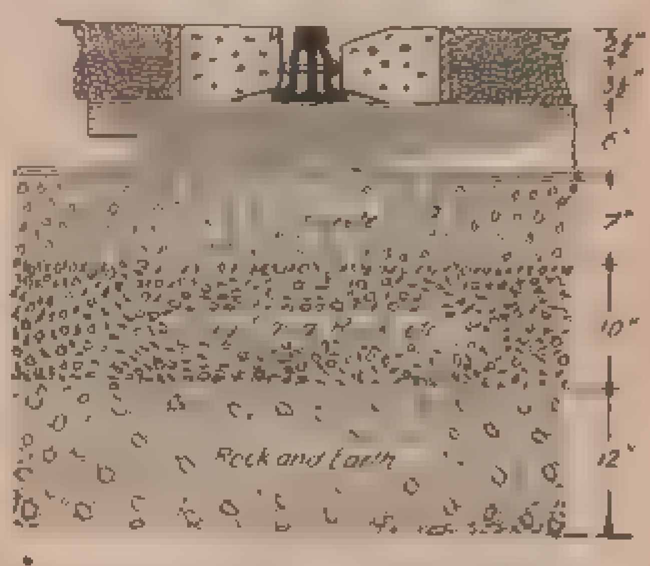


Fig. 34


Asphalt Pavement
Brick Pavement
Stone Pavement
Portland Concrete

FIG. 35


3" Broken Stone
2" Broken Stone

FIG. 36

lined, the joints secured, and the broken stone or concrete brought up to the paving.

**38.** Fig. 34 is an example of a roadbed construction on a weak subsoil. A trench 36 inches deep and the width of the tracks is dug and, as shown by the figure, it is filled to a depth of 29 inches with successive layers of 12 inches of hard earth and rock well beaten down; 10 inches of earth, pebbles, clay, sand, and rocks, well tamped; 7 inches of new concrete; and 6″ × 8″ × 8′ hard pine ties, previously boiled in asphalt, are laid on the concrete to take 80-pound **T** rails.

**39.** Fig. 35 shows the construction used by the Twin City Rapid Transit Company, operating in St. Paul and Minneapolis, for tracks with stone, brick, or asphalt pavement. The rails rest on longitudinal concrete beams tied together by a bed of concrete. Cast welded joints 16 inches long and weighing 190 pounds are used. The cast joint is especially shaped so as to interfere as little as possible with the paving. The rails are 8-inch shanghai **T** type, weigh 79 pounds per yard, and are in 60-foot lengths.

**40.** Fig. 36 shows a construction used for double-track work with stone pavement in Pittsburg. The rail is 90-pound girder in 60-foot lengths. The foundation is of broken stone, and drainage is provided by 3-inch drain tiles placed between the tracks, as shown. The gauge of the track is, in this case, 6 inches wider than standard, being 5 feet 2½ inches.

**41.** Fig. 37 shows a very heavy track construction with concrete, used in Philadelphia. The track is supported on cast-iron chairs provided with screws for adjusting and holding the track to gauge. The chairs are spaced 5 feet apart and are bedded in concrete, as shown; a solid sheet of concrete 4½ inches thick, together with tie-rods at regular intervals, prevent any spreading of the concrete stringers on which the rails are carried.

**42.** Fig. 38 shows a section of track construction in Detroit that combines the concrete-beam feature and the steel

. . . more as a tie-rod for keeping
. . resting place for the rails.
. . goes to a depth of only
. . . be as deep as 2 feet.

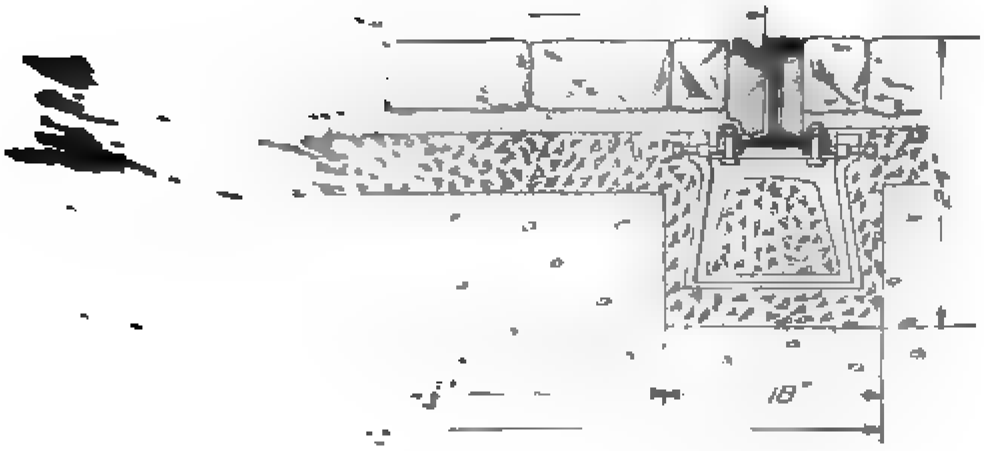


Fig. 37

. . . struction adopted in New Orleans
. . . and yielding. Several of the

. 38

. . . built on neutral ground between
. . . they are not subjected to the wear

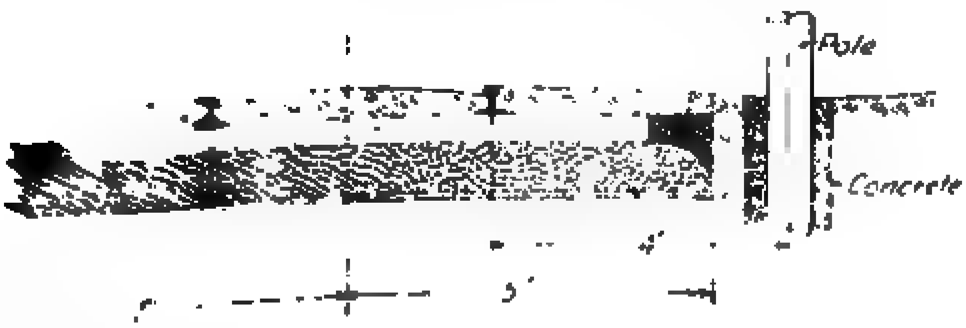


Fig. 39

wagon traffic. This location of the track admits
. . . T rail as shown in Fig. 39. The first step is
. . trenches, one for each track about 2 feet deep
. . . wide. On the bottoms of the leveled trenches

are laid lengthwise $1\frac{1}{4}$-inch yellow-pine boards; these act as the foundation for a layer of $1\frac{1}{2}$-inch broken stone, on which the $6'' \times 8'' \times 8'$ creosoted yellow-pine ties rest, 2 feet between centers. The space between the ties is filled partly with broken stone and partly with gravel that goes to the top of the ties. On top of the gravel is put a layer of soil in which grass is sown, so that a few months after the work is done the whole neutral ground is grass-grown—a feature that almost does away entirely with the clouds of dust ordinarily raised by a car in course of rapid transit. The plank construction on the bottom of the roadbed prevents the tendency of the track to sink into the soil and cause undulations in the surface line of the rail.

**44. Use of Plank to Secure Even Pavement.**—In some classes of track construction, where there is very little space between the upper surface of the ties and the under side of the pavement in which to place a solid foundation for the pavement, an uneven road surface is almost sure to result because of settlement between the ties. The roadbed should be designed so that the pavement will have an even and secure foundation, but in cases where this is not possible it has been found advantageous to lay the pavement on rough hemlock planks that have been placed on the ties; a thin bedding of sand is placed beneath the pavement. The planking affords an even support but, like the ties, it has to be renewed in course of time.

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### THIRD-RAIL ROADS

**45. Form of Third Rail.**—In practically all the third-rail roads so far installed, the conductor rail has been of the ordinary **T** section. Other sections have been proposed, one of which, suggested by Mr. W. B. Potter, is shown in Fig. 40. It is not necessary to have the same degree of stiffness in a conductor rail that is required in a track rail, and the plain rectangular section shown in Fig. 40 was designed with the idea of making the rail as easy to roll as possible; also, to provide a simple means of clamping the rails at joints without

drilling holes through them. A rail of this section weighs about 98 pounds per yard. So far, however, special shapes have not been introduced to any extent, as the standard T sections are more easily obtained.

**46. Location of Third Rail.**—The third rail may be located on either side of the track, as may be most convenient; on double-track roads, the two third rails are usually placed between the tracks. At different points on a road, it may be found advisable to change the location of the rail from one side to the other, but as both sides of the cars are equipped with collecting shoes, this makes no difference so far as the collection of current is concerned. The relation of the third rail to the track rails varies on different roads and is determined largely by the clearance that must be allowed for locomotives or rolling stock that may be run over the road. Where steam locomotives are run over a third-rail road, the conductor rail must be located so as not to interfere with the locomotive

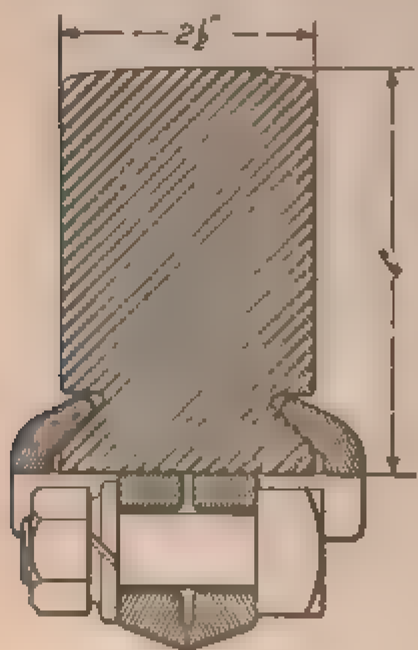



FIG. 40

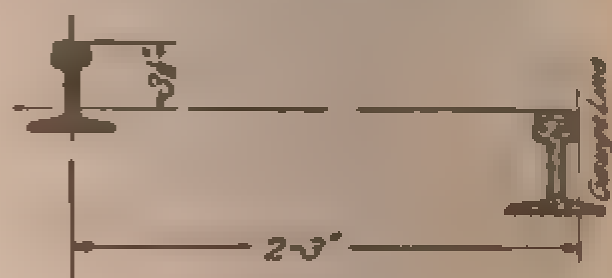



FIG. 41

cylinders, which usually project farther than any other part. Fig. 41 shows the location recommended by a committee of the Master Car Builders' Association. The center of the third rail is 2 feet 3 inches from the gauge line of the nearer track rail and the tread of the third rail is 3½ inches above that of the track rail. The size of the third rail for a given road is determined, to a certain extent, by the amount of current required for the cars. Weights less than 60 pounds per yard are seldom used unless the traffic is light, and very often the rail is of the same weight as the track rails.

60-foot rails are desirable because of the decreased number of joints.

**47. Protection of Third Rail.**—On many roads, the third rail is not protected in any way, but there is a growing demand for protection of some kind that will make it difficult for accidental contact to be established between the third rail and ground or track rails. Also, protection is desirable to prevent the accumulation of ice or snow on the rail. Fig. 42 shows a simple method of protection as used on a number of elevated roads. Planks are run parallel to the rail and project about 2 inches above the head; anything accidentally dropped across the rail is prevented from making contact by the projecting planks. This


Fig 42

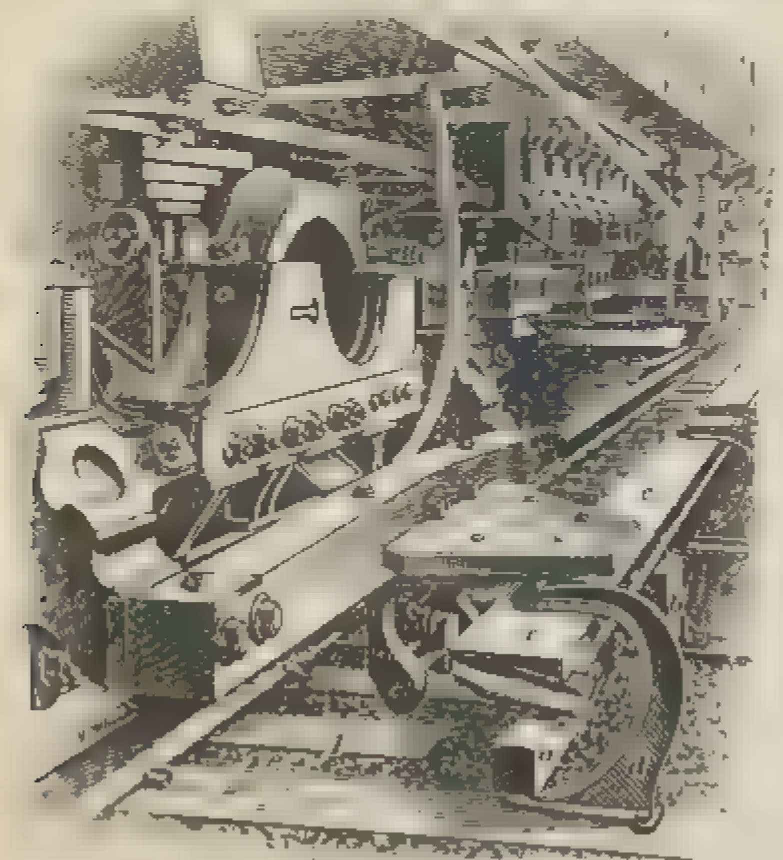


Fig. 43

method does not protect the rail from snow or sleet, nor does it afford as great a measure of safety as the plan shown in Figs. 43 and 44, which represents a protected third rail used by the General Electric Company.

Fig. 43 shows the general arrangement of the third rail and collecting shoe with reference to the motor truck, and Fig. 44 shows the details. The conductor rail *a* is supported on reconstructed granite insulators *b* and is covered by a

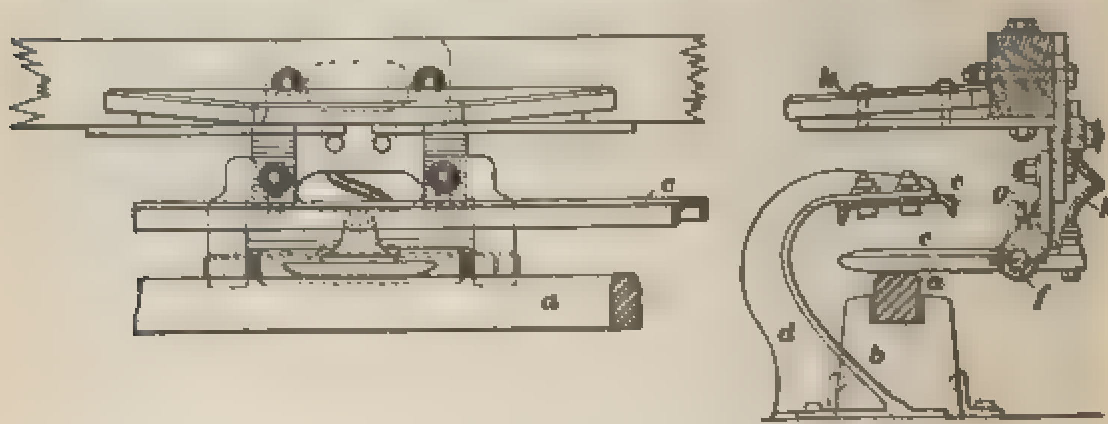


FIG. 44

channel iron *c* fastened to brackets *d* that rest on ties projecting about 18 inches beyond the regular ties. The shoe *e* is in the form of a flat plate hinged at *f* and held in contact with the rail by the spring *g*; flexible cable *h* connects the

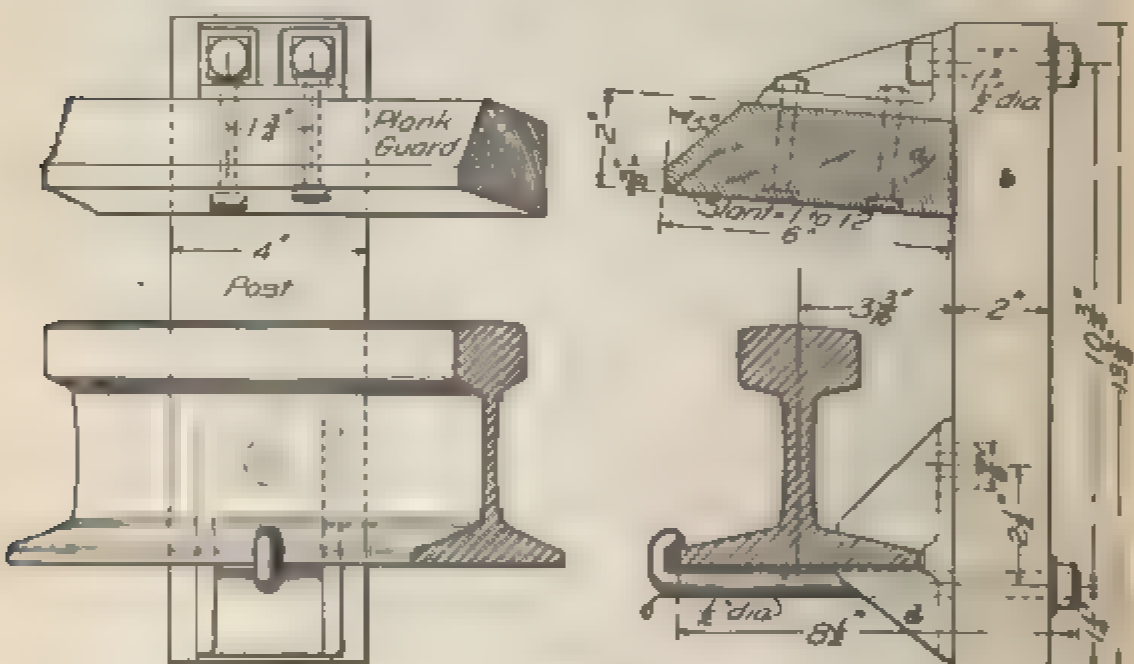



FIG. 45

shoe to the main trunk wire running to the controlling apparatus. A projecting wooden guard *k* prevents accidental contact with the parts of the shoe. With this construction, it is almost impossible for any one to step on the third rail

or for pieces of metal to drop across it and the track rails, thereby causing a short circuit.

**48.** A modification of the method just described is shown in Fig. 45, which represents the method of rail protection used on the Wilkes-Barre and Hazleton road; a very similar method is used on the New York subway, and in both cases the style of shoe shown in Fig. 44 is employed. The guard consists of a 2-inch pine plank *a* fastened to 2″ × 4″ oak posts *b*, as shown. The posts are supported from the foot of the rail by clamping them by means of a special bolt *c* and a bearing casting *d*, formed to fit the foot of the rail. The construction as a whole is much cheaper than that shown in Fig. 43 and affords equally good protection. Fig. 46 shows the arrangement of the third-rail guard used on the New York subway.

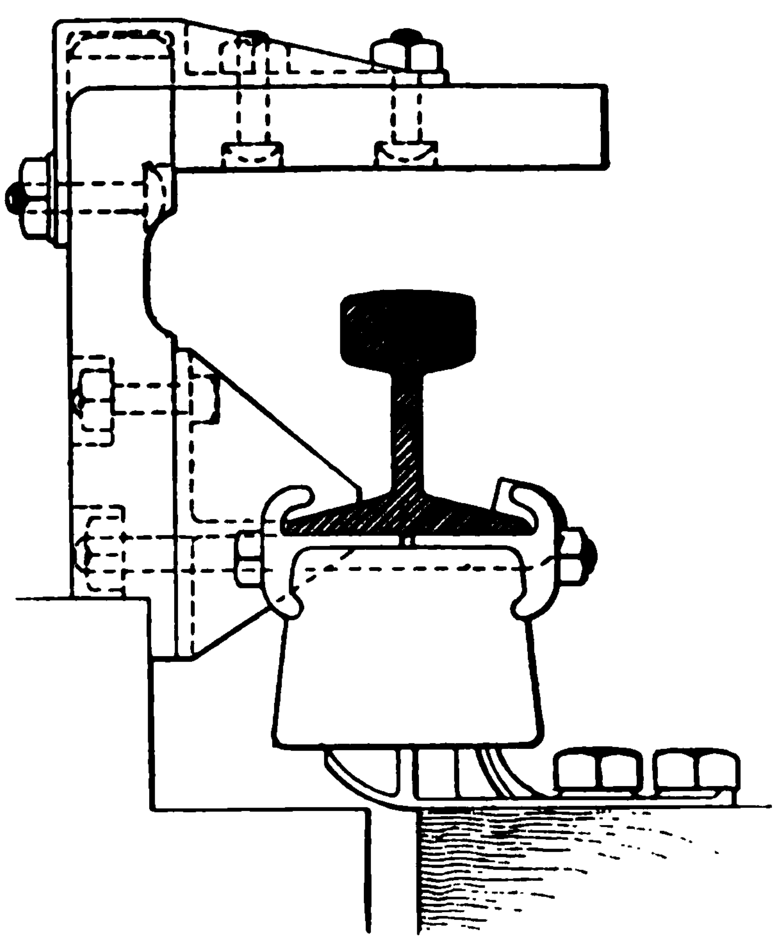


FIG. 46

**49. Arrangement of Third Rail at Highway Crossings.**—Where a third-rail road crosses a public highway, it is necessary to break the contact rail and make connection by means of a cable carried across either overhead or underground. The connection is nearly always made by means of underground cable, which is much shorter than an overhead one could possibly be. Fig. 47 shows a typical crossing. The contact rail *a* is provided with cast-steel, inclined, approach blocks *b*, *b* that allow the shoes to glide on to the rails without shock. At *c*, a cable is attached to the rail and is carried underground to *d*, where it connects to the rail again, thus preserving the continuity of the conducting system; the cable should have a cross-section equivalent, in carrying capacity, to that of the rail;

1,000,000-circular-mil, lead-covered, paper-insulated cable is often used for this purpose.

Various methods are used for running the cable; one very common plan is to incase it in tile and fill the tile, at the ends, with insulating compound that will prevent water from entering. The cable must be thoroughly insulated from the ground, otherwise there will be leakage and consequent electrolytic action that will eat away the cable in course of time. Fig. 48 shows a method used on a third-rail road in

FIG. 47

Michigan, where the cable is carried through a heavy porcelain insulator set in a cast-iron pipe. The strands of the cable are soldered into a terminal casting and after the lower part of the insulator has been plugged with oakum the space is filled with insulating compound that prevents moisture from entering the paper insulation of the cable, which, in this case, has a lead sheath covered with jute treated with asphalt. A brass cap is bolted to the cable terminal and from it two 300,000-circular-mil flexible bonds connect to the

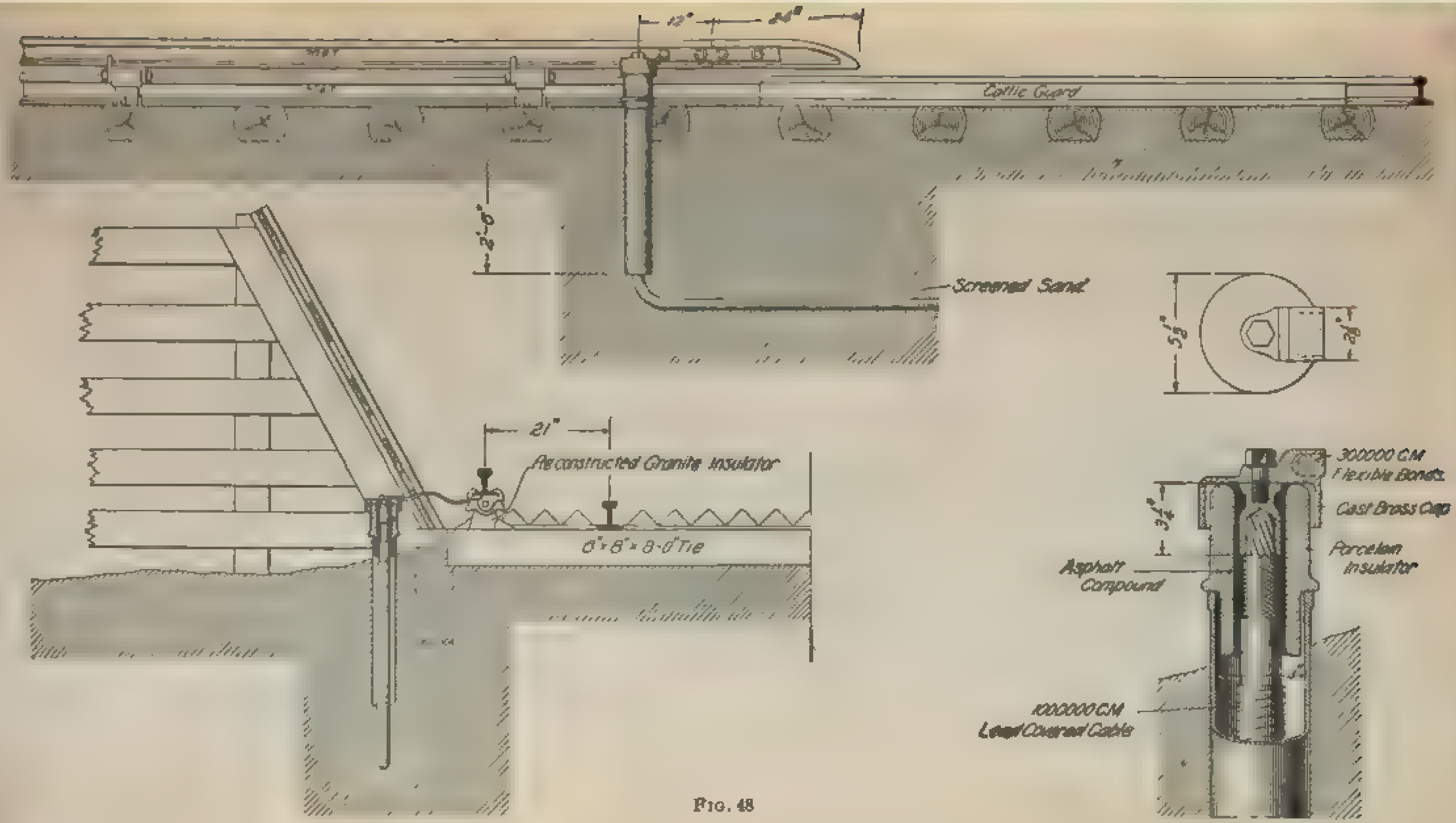
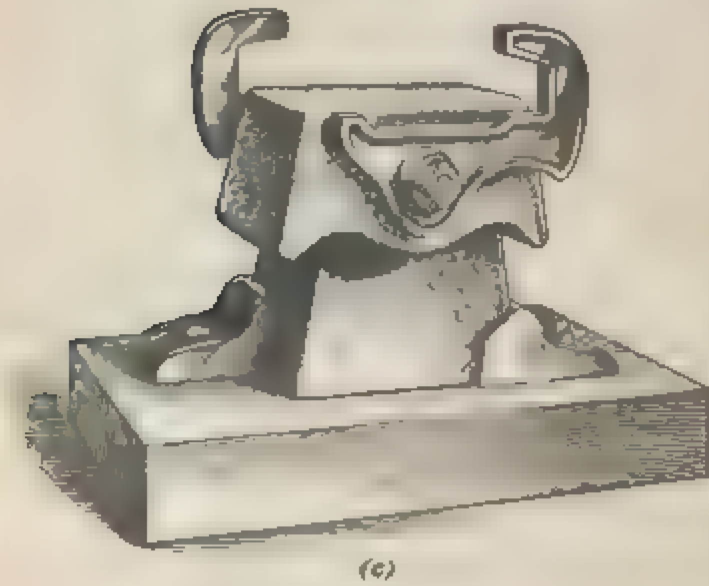

12"
24"
Cattle Guard
2'-0"
Screened Sand
21"
Reconstructed Granite Insulator
6"×8"×8'-0" Tie
300000 C.M.
Flexible Bonds
Cast Brass Cap
Porcelain
Insulator
Asphalt
Compound
1000000 C.M.
Lead Covered Cable

Fig. 48

rail. The cable is bedded in screened sand after it leaves the pipe; with this construction there is little danger of electrolytic action on the cable sheath.

(a)

(b)



(c)

FIG. 49

**50. Third-Rail Insulators.**—The third rail should be thoroughly insulated from the track rails and ground by being mounted on suitable insulators that are strong mechanically and allow the conductor rail freedom for expansion and contraction. They have, in many cases, been made of specially treated wood provided with an iron cap for the rail to rest on, but in the best construction special insulating material, such as reconstructed granite, is used. Fig. 49 shows three common types of insulator in which the insulating material is of reconstructed granite. In (*a*) and (*b*), the rail rests on an iron cap and is prevented from moving sidewise by means of lugs; in (*c*), the rail rests on

the granite block and is restrained sidewise by special castings held by a bolt passing through the molded granite. All fastenings should allow a certain amount of up-and-down play; the weight of the rail is amply sufficient to hold it in place, and if it is too tightly fastened undue strains will be thrown on the insulators. Insulators are usually placed on every fifth tie, which is made about 2 feet longer than the others.

**51. Third-Rail Leakage.**—Tests have shown that the current leakage per mile of third rail is very small if proper precautions are taken; very often the leakage from a poorly insulated underground cable at a road crossing will amount to more than that from several miles of third rail. Tests by Mr. R. P. Leavitt,* on the Albany and Hudson road, on a section of third rail entirely disconnected from all cables at crossings, showed a leakage varying from .057 ampere per mile, after a rain lasting 20 hours, to .023 ampere per mile in hard freezing weather with light snow on track. Tests made on the whole road, including cables at crossings, showed an average leakage of about .5 ampere per mile and investigation showed that the greater part of the leakage was due to defective insulation of crossing cables. The insulators were of specially prepared wood with an iron cap.

**52. Sleet Cutters for Third Rail.**—Where the head of the third rail is not protected from rain or snow, as, for example, with the ordinary unprotected rail or with the arrangement shown in Fig. 42, considerable trouble is caused by the accumulation of snow and ice. A rain followed by freezing forms a thin film of ice on the rail, which is very difficult to remove and is a non-conductor of electricity. When third-rail roads were first operated on a large scale, numerous tie-ups resulted from this cause, but experience has shown that the sleet can be removed by suitable appliances. In some cases, brine is sprinkled on the third rail from a tank carried on a car, but a better method is to use

*Street Railway Journal, Vol. XXI, No. 16.

some form of sleet cutter. Fig. 50 shows the sleet-cutting device used on the Manhattan Elevated Railway, New York. It is fastened to an extension of the beam that supports the collecting shoe so that the cutter, or scraper, is directly in advance of the shoe. The cutter consists of a number of steel plates *a* cast into a block *b*, the plates being set at an

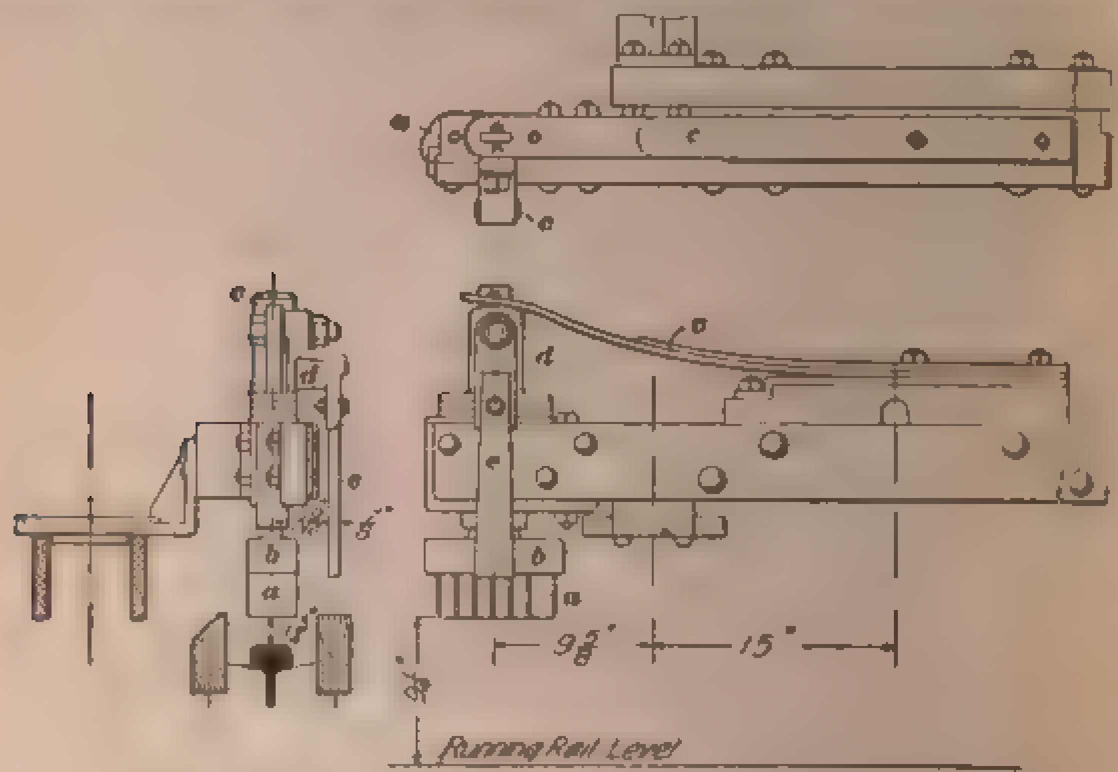



FIG. 50

angle so that they will slide over any slight projections at the rail joints. The cutter is pressed against the rail by a flat spring *c*, and a cam *d* operated by lever *e* is arranged to hold the shoe up when it is not in use. By moving lever *e* to one side, the shoe can be lowered by the motorman or it can be operated by a tripping device controlled from a central point.

**53.** Fig. 51 shows a style of contact shoe and sleet brush used on the Brooklyn elevated road. The shoe *a* is of the ordinary link type and is suspended from a steel casting *b*, which also forms one of the terminals for the shoe fuse *c*. The other terminal *d* of the fuse is insulated from casting *b*, and to it is attached the cable *e* leading to the controlling devices. The sleet cutter consists of a stiff brush *f* made of

steel ribbon $\frac{1}{8}$ inch wide, No. 23 B. & S. thick, set in a hard maple block. The brush is insulated from its guide bar and is pressed against the rail by spring *g* with a pressure of about 75 pounds. When not in use, the brushes are raised from the rail and held up by throwing handle *h*.

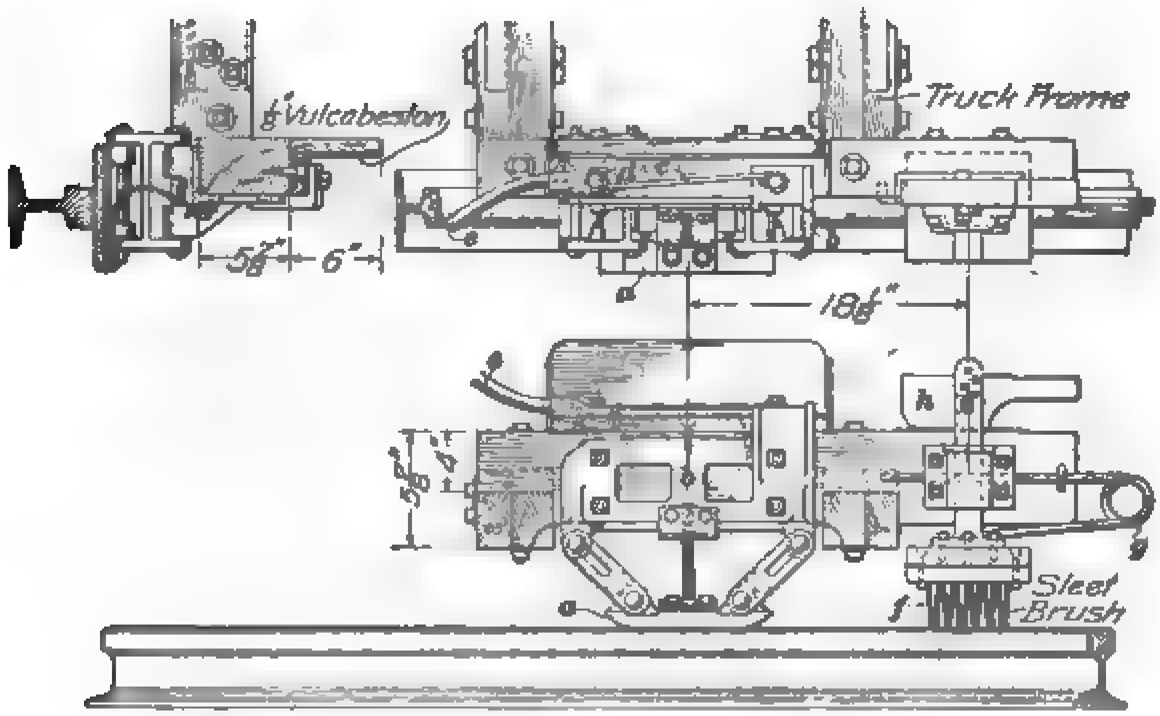



Fig. 51

On third-rail roads four shoes are placed on each car, one on each side of each truck, so that the car will always be supplied with current no matter on which side of the track the third rail may be placed.

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### CONDUIT ROADS

**54.** Fig. 52 shows a conduit construction, used in New York, that may be taken as typical of this class of roads. The rails are supported on heavy cast-iron yokes *a* spaced 5 feet apart; every third yoke is provided with handholes, as shown, and carries the insulators *b* to which the conductor rails *c*, *c* are fastened. The conductor rails are thus supported at intervals of 15 feet. Fig. 53 is a larger section of one of the handhole yokes, showing the method of supporting the conductor rail. The conduit between yokes is made of concrete filled in around a sheet-iron form that is afterwards

some form of sleet cutter. Fig. 50 s
device used on the Manhattan Elevate
It is fastened to an extension of the
collecting shoe so that the cutter, o
advance of the shoe. The cutter co
steel plates *a* cast into a block *b*, the

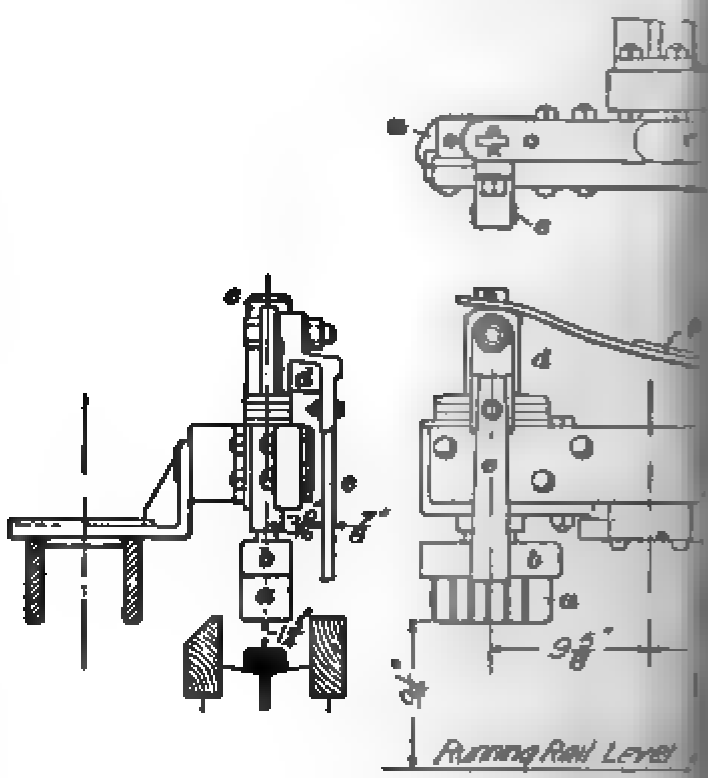


FIG. 50

angle so that they will slide over
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flat spring *c*, and a cam *d* operated
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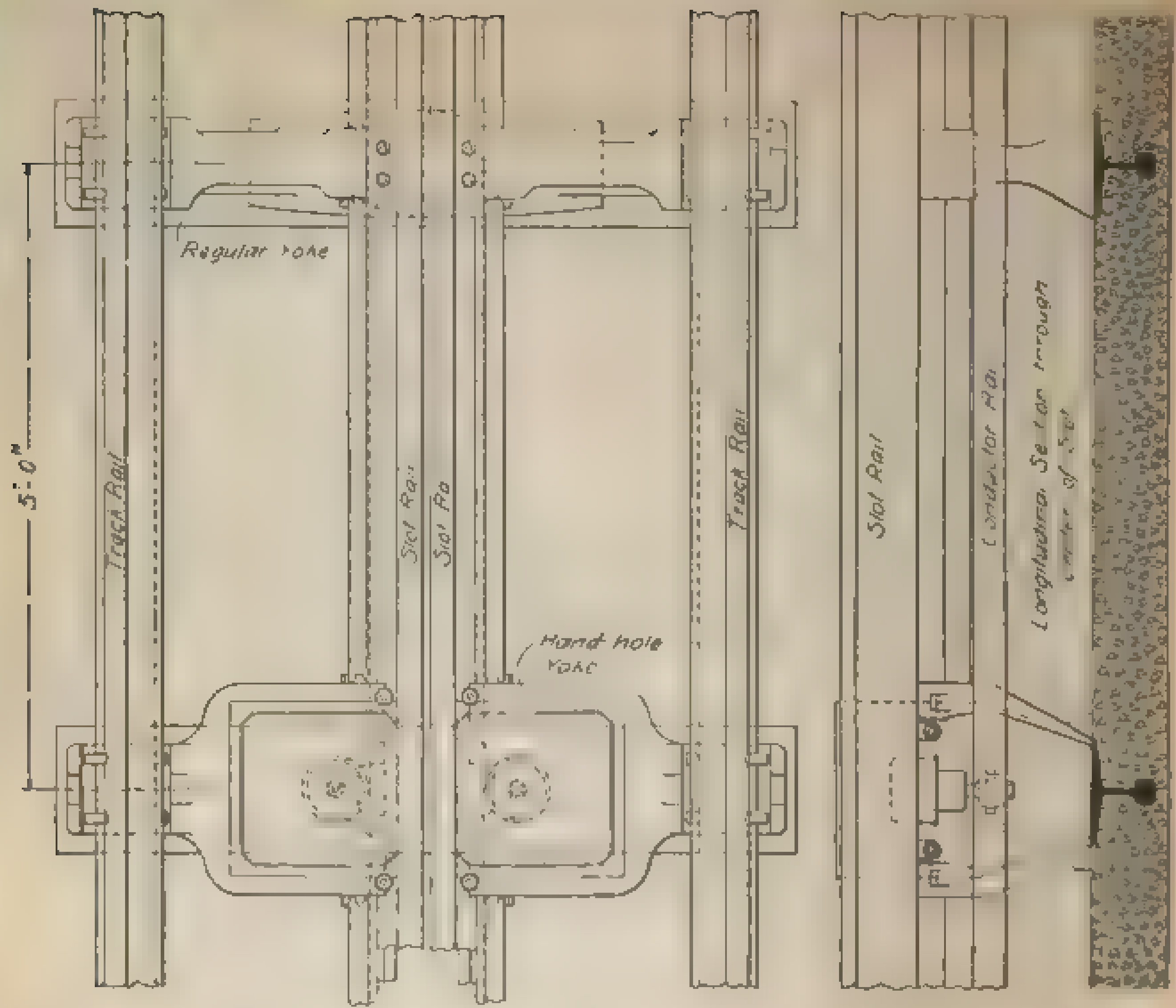
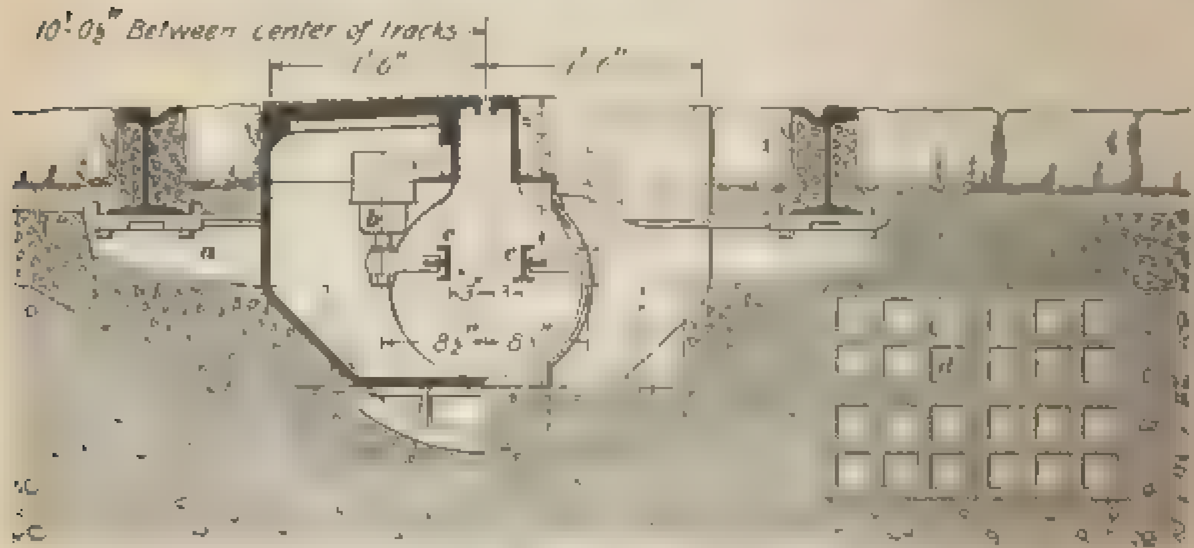
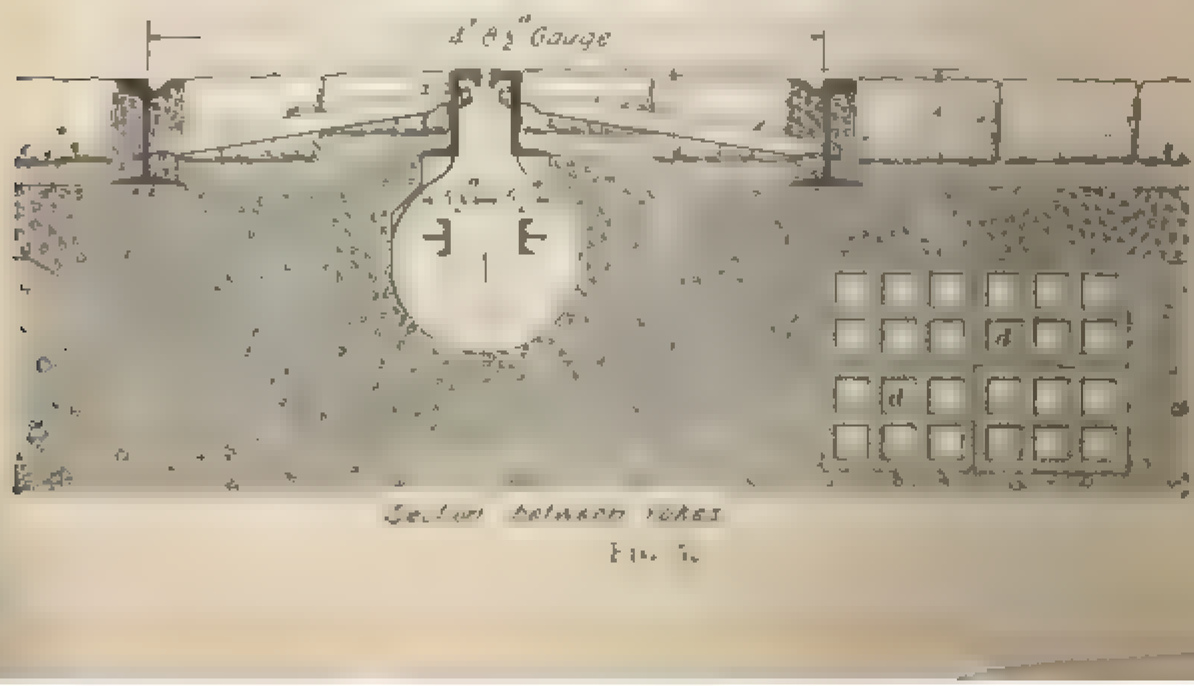



Half Section through Hand-hole Yoke




Section between Yokes

Fig.

removed. Each manhole is connected to the sewer by a 6-inch pipe and the outgoing and return feeders supplying different sections of the conductor rails are run in terra-cotta ducts *d*, *d*, Fig. 52. To facilitate the installation of new feeders or the repair of old ones, manholes are provided every 400 feet.

**55.** Mud accumulates in the main conduit very fast, and if not promptly removed gives trouble. The main conduit must be cleaned about once a month in the summer time, and perhaps oftener than this during the winter. By means of special scrapers, the mud is drawn into the manhole and then lifted out and carted away.

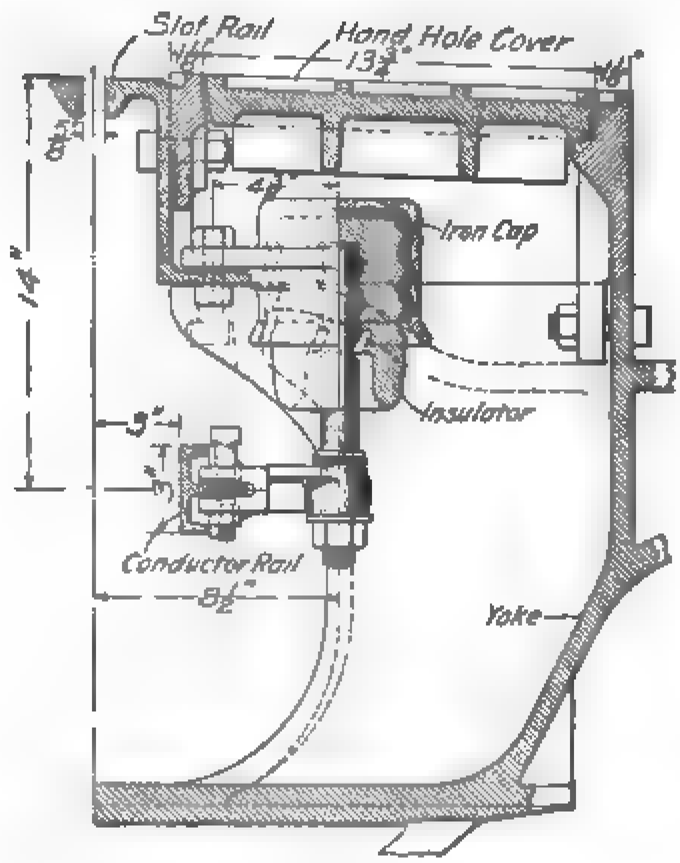


FIG. 53

The conductor rails are not continuous, but are divided into sections about a mile long, and each section is fed by its own feeder from the power house. There is no electrical connection between these feeders, so that the road is cut up into insulated sections, and trouble on one section is not so liable to interfere with the traffic on the others. Each feeder has its own switch and circuit-breaker, and in case a ground occurs on one section the circuit-breaker on that section flies out and the attendant in charge at the power house can tell exactly on what stretch of track the trouble is. Splitting the road into sections supplied by individual feeders also has the advantage that in case of a block on the road, the simultaneous efforts of all the motormen to start their cars will not cause heavy overloads in the power house,

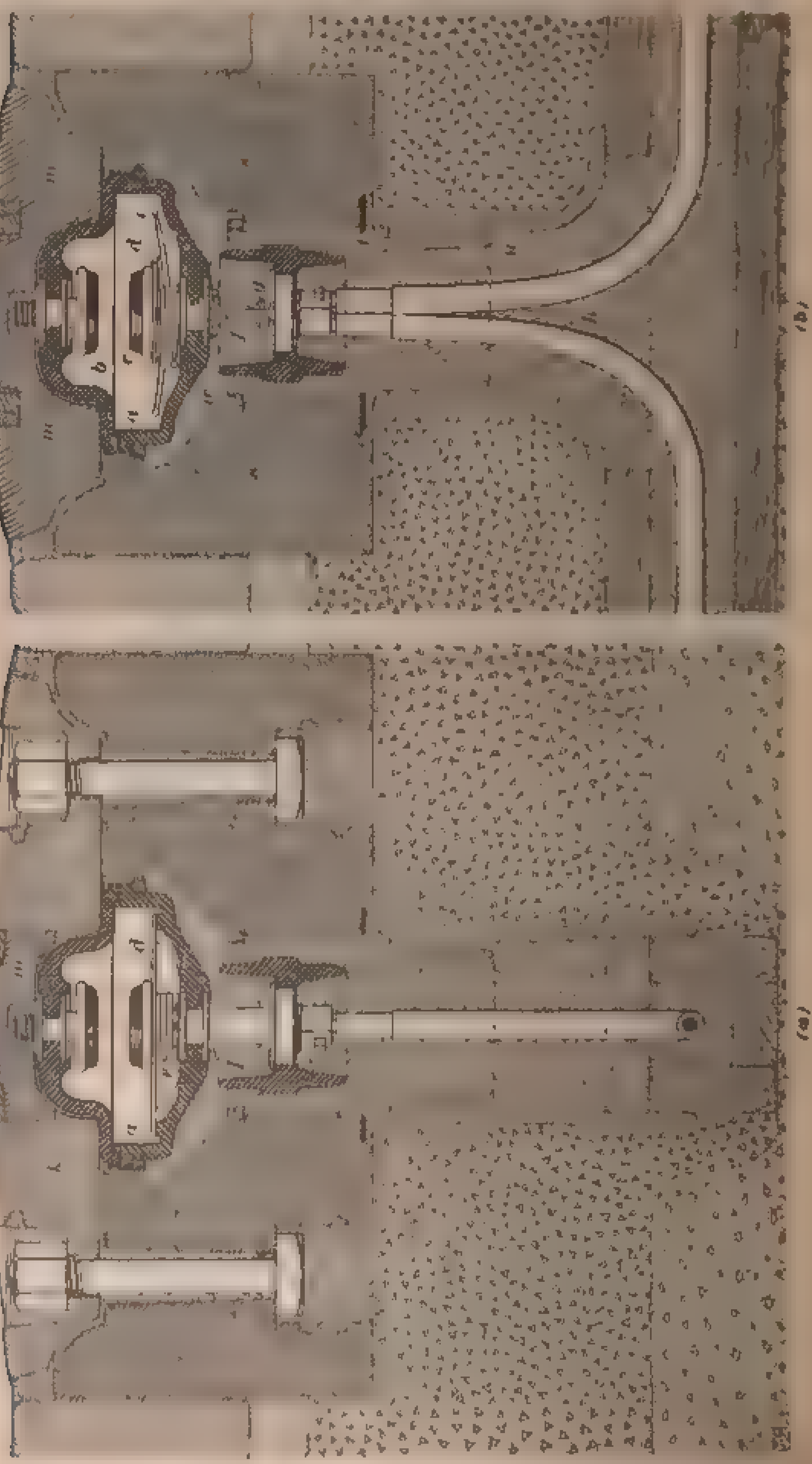



FIG. 54

because the switchboard attendant has every section of the road under his control and can compel the cars to start up, one section at a time.

It is necessary that the yokes be well designed to resist the pressure of the earth (which is packed down by the heavy traffic) and the very heavy pressure in cold climates, due to the freezing of the soil, with its accompanying expansion. Wrought iron, steel, and cast iron have been used for this purpose, the latter, perhaps, being the most common. When yokes of light weight are put in, trouble is often occasioned by breakage. The conduit may be lined with steel plates or it may be constructed on the sides of concrete alone; in some cases the metal yokes have been replaced by concrete, but the best practice is to use heavy castings ranging in weight from 200 to 400 pounds or more, according to the depth of the conduit and the character of the wagon traffic expected.

## SURFACE-CONTACT ROADS

**56.** As very few of these roads have been put into actual operation, the description here given will be confined to the system of the Lorain Steel Company, as successfully operated at Wolverhampton, England. The general principles of this system have already been described, and as the track rails and roadbed are installed in the same way as for an overhead system, it will only be necessary to explain the construction of the contact switches and the method of collecting current from them. Fig. 54 shows longitudinal and transverse sections of the contact switches placed between the rails, and Fig. 55 shows the relation of one of the magnets on the car, to the parts of the switch. The switch contacts, Fig. 54, are contained in a water-tight vulcabeston case *a* and take the form of carbon disks, *b* being fixed and *c* movable. The lower contact *c* is attached to an iron plate or armature *d* that is $1\frac{3}{4}$ inches long, 2 inches wide, and $\frac{1}{8}$ inch thick, and connected to the terminal clips *f* through a folded copper strip *e* that serves as a flexible connection and also guides the armature when it is drawn

upwards by the magnets on the car. The feeder cable connects to the fixed clip *g*, so that when case *a* is in place, contact *c* connects to feed-wire *h*. The cover consists of four parts, *k*, *l*, *m*, and *n*; parts *k* and *l* are of cast iron and *m* and *n* of hard manganese steel, which is practically non-magnetic. Piece *n* takes the wear of the collecting shoe and is renewable, being held in place by lead run in around it. The switch contact case is fastened to plate *m*, so that by removing the cover the whole case can be disconnected

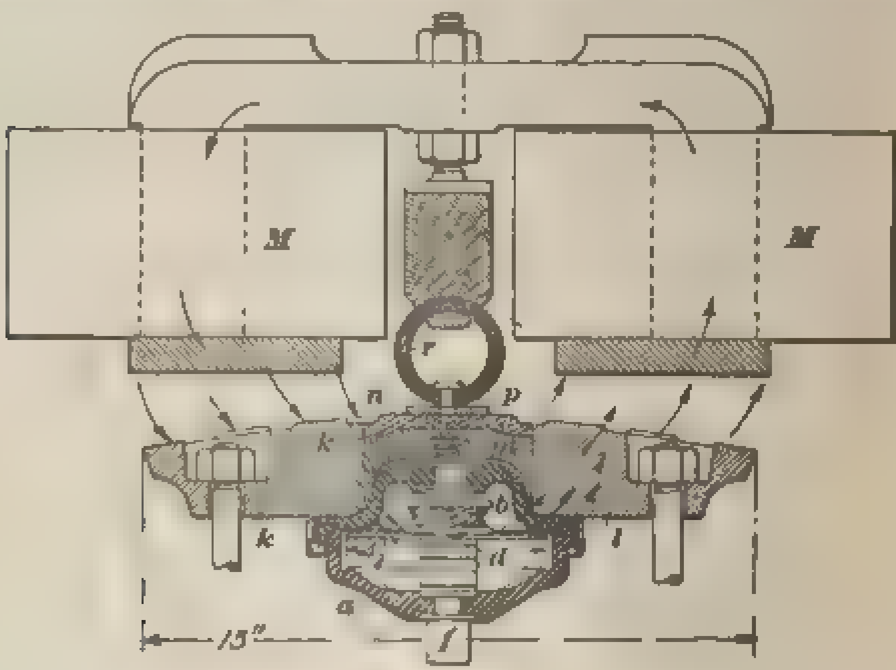



FIG. 55

from the feed wire. The cover is bolted to a strong block *s s* of reconstructed granite and the feed-wire passes up through a cast-iron sleeve *t* that fits into a Y casting *u*; *t* and *u* are filled with insulating compound. Space *u* is filled with a heavy insulating oil that prevents moisture from accumulating around the live terminal *g* and thus avoids surface leakage. The contact studs are placed 10 feet apart.

**57.** The operation of the system will be understood from Fig. 55, where *M M* represents one of the magnets; the parts of the switch are lettered to correspond with Fig. 54. Six magnets are suspended under the car, extending over a space of 16 feet and, since the studs are only 10 feet apart,

the forward switch is operated before the back one is dropped and arcing at the switch contacts is avoided. The pieces of manganese steel *m*, *n* between the side blocks *k*, *l* are practically non-magnetic; hence, when a magnet is over a switch, as in Fig. 55, the lines of force take the path indicated by the arrows and pass through the light armature *d*, which is drawn up, thus bringing the carbon contacts together. As soon as the magnets move from the stud, armature *d* drops; and since the contacts are of carbon there is very little danger of their sticking. The collecting shoe consists of a flat copper strip *p* about 12 feet long bent up at each end and fastened to a piece of heavy rubber hose *r*, which provides pressure between the shoe and the studs and at the same time permits considerable flexibility. The shoe is long enough to bridge across two contact studs, thus providing a continuous collection of current. The magnets are compound wound. When the car is at rest, the shunt winding keeps the contact switches closed, so that the car can be started; the series winding provides excitation in case the voltage becomes too low for the shunt winding to operate the switches; it also holds the switches more firmly in contact as the current taken by the car increases. An eight-cell storage battery is provided on each car so that the series winding can be excited when the car is started for the first time or in case the power is shut off the line temporarily.

# LINE CALCULATIONS

## ECONOMICAL USE OF FEEDERS

**1.** There is no problem involving as little prospect of ever having general rules laid down to cover all cases and all conditions as the problem of calculating the most economical amount of copper to install and the best method of disposing that copper to meet the requirements of a given street-railway service. It is true that the present practice of dividing the line into insulated sections has, to a certain extent, simplified the work of calculation, because each section can be considered as an independent line governed by its own local conditions of load. If these conditions of load could in any case be laid down with certainty, the problem for any particular case would be solved; but once solved for that case, the solution would be of little use to the engineer for application to other cases, because it is almost impossible to find any two roads or even any two sections of the same road that call for the same conditions of load, and therefore for the same distribution of copper. During one part of the day the heaviest load might be on one part of the line and later in the day it might be on a section several miles away. Again, there may take place gradually a general shifting of the load more serious than a daily or weekly shift, due, possibly, to changes of attractions from one end of the line to the other, by a shift in the field of suburban improvements. Though overhead work may be installed under a design that meets satisfactorily almost every requirement of the present service, subsequent changes, such as the development of suburban property, may throw the system completely out of balance. The only thing to do then is

to go over the work again and put copper where it is needed. But it is now a well-known fact that in promiscuously putting up copper, although it may be placed with good judgment from an electrical point of view and successfully fulfil its mission of raising the voltage to its normal value at the desired point, it can be put at a net loss to the company. Copper is expensive, and in the effort to lessen the loss in the line, it is an easy matter to get so much copper strung that a condition arises where the money invested in copper might be more profitably invested in other ways, as, for example, in the installation of boosters or storage batteries.

**2.** The conditions that confront the engineer, then, when he proposes to improve the service by stringing more feeders are as follows: By thus raising the voltage, a certain amount of energy is saved by reducing the line loss, and the saving in watts or horsepower can be approximately calculated. By knowing what it costs to produce a unit of energy at the power house, the direct saving effected by the increase of copper can be at once obtained, and by knowing the cost of the additional copper installed, including the cost of construction, the interest on the cost of the copper may be computed. The rule that it pays to install more copper to raise the voltage, if the cost of the watts saved in a year exceeds a year's interest on the cost of the additional copper put up, is one that should always be kept in mind. It must not be forgotten, however, that the above limiting condition expressed in the form of an equation (interest on the cost = value of energy saved) does not include all the elements that modify the equation. When the feeding system is improved, it brings about a saving in a direct way; it makes the loss in the line less, and effects a saving in an indirect way that is just as important; for, by keeping up the voltage and thereby increasing the efficiency and speed at which the cars run, it not only decreases the number of cars necessary to conform to the conditions of a certain time table, but by improving the service it attracts travel, especially in cases where there is a competing road. Even in cases where there

is no competing road, an improvement in the service draws travel. Calling $Q$ the interest on the cost, $W$ the value of the energy saved, and $S$ the money returned per year as a result of the raising of the E. M. F. by the additional copper, the modified equation will read (the present one reads $Q = W$) $Q = S + W$. This equation is more in favor of the added copper and conforms more to the true state of affairs.

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## EXAMPLES OF FEEDER CALCULATION

**3.** In the transmission of current for electric railways, as in other cases of electric transmission, the loss or drop in the line is usually limited. If the loss is large, a comparatively high-resistance line with a corresponding small amount of copper can be used, but a large line drop means a low voltage at the cars unless the voltage at the station is automatically increased as the load increases. Low line voltage makes it hard for the cars to maintain their schedule and always gives rise to trouble with the motors, to say nothing of the actual cost of the power wasted in the line. It is seldom that the average drop is less than 10 per cent. (50 volts), and in a great many cases it runs much higher than this; if feeding is accomplished through boosters, the line drop may be as great as 200 volts. These figures are for the average drop, and the maximum drop may at certain instants be as high as three or four times the average if the load is of a very fluctuating character.

**4.** The weight of the rail is fixed by traffic considerations, so that an approximate estimate of what the drop in the return circuit will be can be formed at the outset. The balance of the drop will then give that allowed for the feeders, and they should be designed to conform to this as nearly as possible. Feeders designed under this condition seldom fail to fulfil the requirements of the average drop. There is a great difference between the maximum and average loads in the stations, and the smaller the station, the greater is the difference liable to be. For this reason, the

average drop and maximum drop may be widely different. Take a case where the road operates only two or three cars and the load fluctuates between zero and the maximum several times in a minute. Before the size can be assigned to the feeders, the average load that each feeder has to look after must be approximately known or ascertained. In doing this, it is very convenient to divide the line into sections, assign to each section the load that probably will be on it, and proportion the feeders accordingly.

**5.** When the size, number, weight of cars, speed, type of equipment, etc. are known, the average current required for any given section of the road can be determined approximately, as described in a previous section and, knowing the current and allowable drop, the size of the feeders can be calculated. For purposes of illustration in the following examples, a current of 25 amperes per car is taken. This is a fair average for a 24-foot body car. Of course the current taken at starting is very much greater than this, but on the other hand when the car is standing still it is taking no current at all, so that 25 amperes may be safely taken. Also, in all examples, the trolley wire is No. 00 and its cross-section is taken as 133,000 circular mils, this being close enough for line calculations; its resistance per mil-foot is also taken the same as that of ordinary soft copper. This is not strictly accurate, because the resistance of hard-drawn copper is slightly higher than that of annealed copper, but it simplifies the calculations to consider them the same, and since the other quantities used in the calculations are necessarily approximate, there is no advantage in considering the slight difference in the conductivities of the two kinds of copper. Single track laid with 80-pound rail is assumed in all cases; the resistance per mile of track (two rails in parallel) will therefore be .028 ohm, assuming that the resistance across joints is no greater than that of an equal length of solid rail. In order to make some allowance for imperfect joints we will add 25 per cent. and take the resistance per mile of track as .035 ohm.

**ROAD FED FROM ONE END**

**6.** Fig. 1 shows the layout of a road 5 miles long. The system is fed from a power station at one end of the line and operates ten cars using on an average 25 amperes each, making a total of 250 amperes. It is specified that the total load concentrated at the end of the line shall not produce an average drop of over 100 volts. If the trolley wire is No. 00, what must be the size of the feeder $BA$?

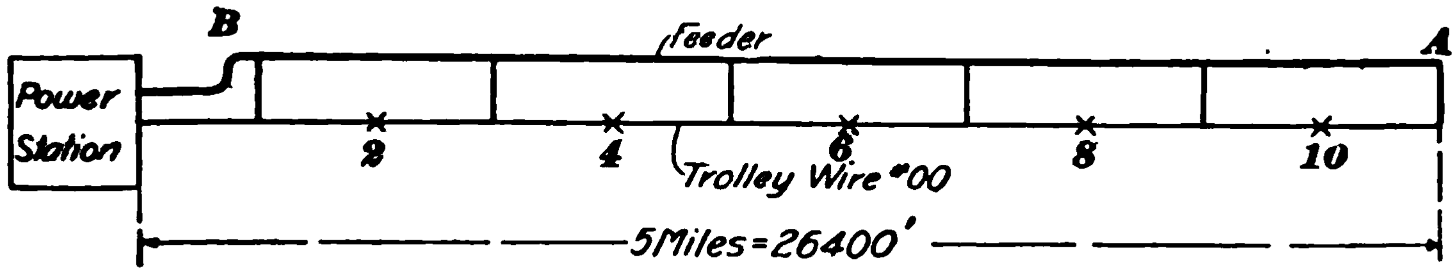


FIG. 1

The road is single track, so that the resistance of the 5 miles will be $.035 \times 5 = .175$ ohm, which resistance, carrying a current of 250 amperes, will cause a drop of $250 \times .175 = 43.75$ volts, leaving a drop of $100 - 43.75 = 56.25$ volts in the trolley wire and feeder. If it is assumed that the conductivity of the copper in the trolley wire is the same as that in the feed-wire, we may use the formula

$$\text{circular mils} = \frac{10.8\,L\,I}{e} \qquad (1)$$

where $L$ = length of wire, in feet, through which the current $I$ is delivered;

$I$ = current supplied;

$e$ = drop in volts.

The number of circular mils given by this formula will be the combined cross-section of the trolley and feeder, because these two wires are tied together in parallel throughout their length. In this case, $L = 26{,}400$ feet, $I = 250$ amperes, $e = 56.25$ volts; hence,

$$\text{circular mils} = \frac{10.8 \times 26{,}400 \times 250}{56.25} = 1{,}267{,}200$$

The trolley wire is No. 00, has an area of cross-section of 133,000 circular mils, and, deducting this from the total cross-section as calculated, leaves $1{,}267{,}200 - 133{,}000 = 1{,}134{,}200$

circular mils as the cross-section required in the feeder; two 500,000-circular-mil cables could be used and the system worked with a drop slightly larger than that calculated.

**7.** It should be noted that in working this example a fair value for the track resistance was assumed and the drop in the track circuit estimated. This was subtracted from the total drop, thus giving the value $e$ used in formula **1**. Formula **1** does not, therefore, in itself take the track resistance into account. It was found that a very large feeder was needed to meet the requirements, which in this case were severe, because the drop was not to exceed 100 volts when all the cars were bunched at the end of the line. In most cases the cars would be moving along over different sections of the line, and thus lessen the drop on the system, because some of the cars would be comparatively near the station. At the same time, conditions arise where the cars may all be bunched at the end. In this case, therefore, it would be well to raise the voltage to 600 at full load at the station, either by using a heavily overcompounded generator, or by means of a booster.

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### POWER HOUSE IN MIDDLE OF LINE

**8.** If the power house were situated at the middle of the line, the amount of copper required would be very much less, as will be easily seen by referring to Fig. 2. The limiting condition is the same as before; that is, the drop

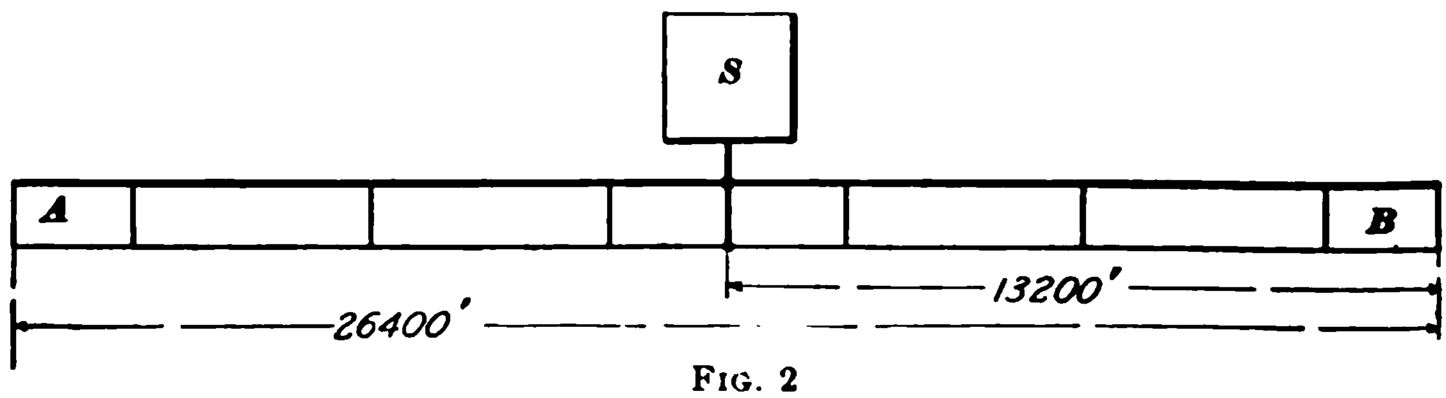


FIG. 2

from $S$ to $A$ or $B$ must not exceed 100 volts when all the cars are concentrated at either $A$ or $B$. If the cars are bunched at either $A$ or $B$, 250 amperes must be transmitted through $2\frac{1}{2}$ miles of track and feeder. Taking the track

resistance as .035 ohm per mile, the resistance of $2\frac{1}{2}$ miles of track will be $.035 \times 2.5 = .0875$ ohm. The drop in the track part of the circuit will, therefore, be $.0875 \times 250 = 21.875$ volts. This leaves a drop of $100 - 21.875 = 78.125$ volts in the feeder and trolley wire. The length of feeder and trolley wire is $2\frac{1}{2}$ miles; hence, by applying formula **1**, the combined cross-section of the two is

$$\text{circular mils} = \frac{10.8 \times 13{,}200 \times 250}{78.125} = 456{,}190$$

The trolley wire supplies 133,000 circular mils of this cross-section; hence, the cross-section of feeder required is $456{,}190 - 133{,}000 = 323{,}190$. Placing the power house near the middle of the line results in a very large reduction in the amount of copper required, and a single 300,000-circular-mil cable would supply the current with as little drop as two 500,000-circular-mil cables in the first example.

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### EFFECT OF DISTRIBUTED LOAD

**9.** So far the feeder problems have been worked out on the assumption that the load was bunched at one end. This is a condition that sometimes arises in practice, but it can hardly be looked on as the ordinary operating condition. In most cases, a number of cars are spaced at fairly regular intervals along the line, each car moving at an approximately

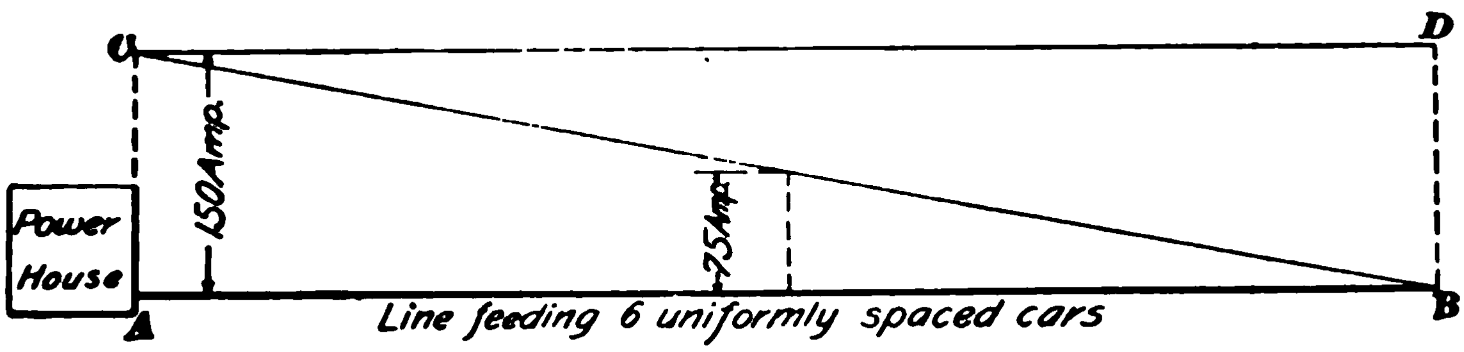



FIG. 3

uniform rate with the result that current is taken off at a number of points that are continually shifting. The load is nearly uniformly distributed and there is a gradual falling off in current from the station to the end of the line. For example, suppose that $AB$, Fig. 3, represents a stretch of line that supplies six uniformly spaced cars moving at a

between the streets is exaggerated in Fig. 4 in order to make the arrangement clearer. The track is represented by the parallel dotted lines, and the two trolley wires are tied together at intervals. Two feeders, represented by the heavy lines, are connected to the trolley wires at points $l$, $m$, and the trolley wire is divided into two sections by means of section insulators $x$, $x'$, each feeding-in point being at the middle of a section. Since the two sections are independent and each is supplied by its own feeder, it will be sufficient to calculate one of the feeders; the other will be the same, because the road is symmetrical. Since the cars are uniformly distributed, the load on each section may be considered as

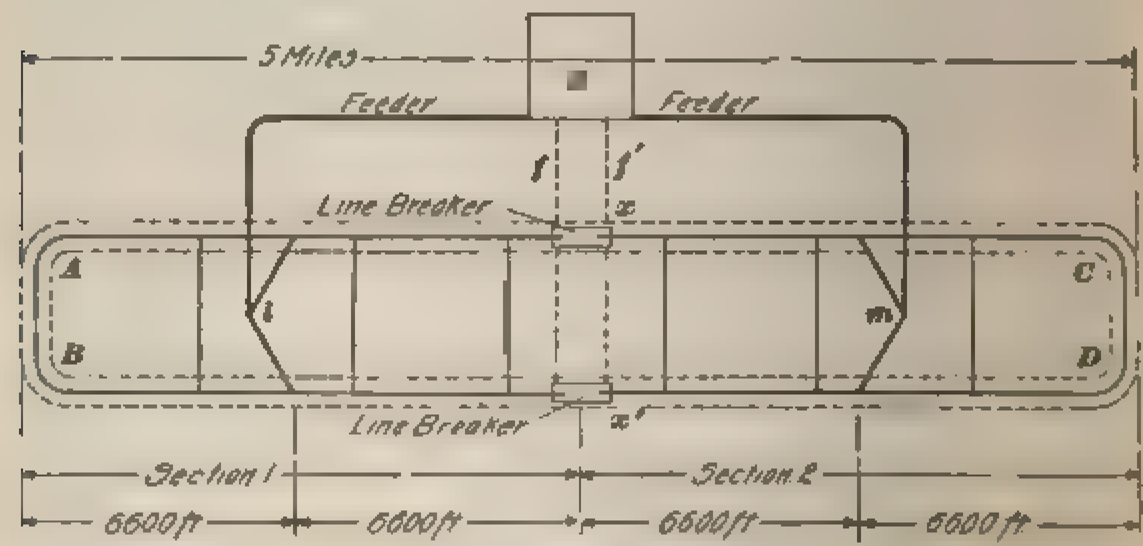



FIG. 4

concentrated at the middle of that section, that is, where the feeders are attached. The drop from the station to the feeding-in points $l$, $m$ must not exceed 50 volts, and a total of ten cars is operated, each taking 25 amperes. The number of cars on each of the two sections will, therefore, be five, and each feeder will have to supply 125 amperes. Since the trolley wire is fed from the middle point of each section and there are no feeders on the end of the section, there will always be more or less drop in the trolley wire itself, but this will not be very great because there will not be more than two cars on any trolley section, and if the drop to the feeding-in points is limited to 50 volts the service will be satisfactory. The length of a section is $2\frac{1}{2}$ miles, or

13,200 feet; a half section is 6,600 feet. The resistance through which the drop of 50 volts is to take place is that of four lines of single rail well bonded together, each line being $2\frac{1}{2}$ miles long. However, the load is uniformly distributed and the total current of 125 amperes can be considered as flowing through $1\frac{1}{4}$ miles of double track. The resistance of 1 mile of single track is .035 ohm and of double track $\frac{.035}{2}$; hence, $1\frac{1}{4}$ miles of double track has a resistance of $\frac{.035}{2} \times \frac{5}{4}$ $= .0219$ ohm. The drop in the rail return is $.0219 \times 125 = 2.74$ volts, and the allowable drop in the feeders $50 - 2.74 = 47.26$ volts. So far as the feeders are concerned, the load is not distributed because they each connect to the trolley wire only at the end, and 125 amperes is carried over the whole length of the feeder. The length of the feeder is 6,600 feet; hence, circular mils $= \frac{10.8 \times 6{,}600 \times 125}{47.26}$ $= 188{,}530$, approximately.

No. 000 B. & S. is too small (167,805 circular mils) and No. 0000 (211,600 circular mils) is larger than the calculated size; however, it would be advisable to use No. 0000 and thus allow for a future increase in load. The drop in the feeder can be calculated from formula **1** transposed to read

$$e = \frac{10.8\,L\,I}{\text{circular mils}} \qquad (2)$$

which for a No. 0000 feeder (211,600 circular mils), gives

$$e = \frac{10.8 \times 6{,}600 \times 125}{211{,}600} = 42.1 \text{ volts, nearly}$$

**12.** In the layout shown in Fig. 4, the trolley wires are not fed on the ends, and if the five cars on one-half of the road became bunched at the end of a trolley section the drop would be considerable. Under these conditions, 125 amperes would be carried 6,600 feet by two No. 00 wires in parallel and the drop in the trolley wire would be, from formula **2**,

$$e = \frac{10.8 \times 6{,}600 \times 125}{2 \times 133{,}000} = 33.5 \text{ volts}$$

**13.** In Fig. 4, suppose that two feeders *f*, *f′*, indicated by the dotted lines, are connected, one to each section, directly from the power house. In practice, it will cost but little to do this, because these feeders are very short and, as shown by the following, the effect on the voltage is beneficial. Consider one of the sections, say, section *1*; it is fed by the regular feeder previously calculated, and, in addition, the feeder *f* runs out directly from the power house and is tapped on the trolley wire at the line breaker. We will find what the drop would be under the most unfavorable conditions, that is, with the five cars on the section bunched at *A*. The whole current, 125 amperes, will have to return to the station through $2\frac{1}{2}$ miles of double track. In the overhead work there will be $1\frac{1}{4}$ miles of feed-wire, and in parallel with this will be the two trolley wires extending back to the station, because the connection of the feeder *f* places the trolley wires in parallel with the regular feeder. Up to the point *l*, therefore, the feeder and the two trolley wires, in parallel, carry the current; beyond *l*, to the end of the line, the current is carried by the two trolley wires alone. It will be assumed that No. 0000 wire is used for the feeder.

The resistance of $2\frac{1}{2}$ miles of double track will be $\frac{.035}{2} \times \frac{5}{2}$ = .0438 ohm, approximately. The drop in the track will, therefore, be $.0438 \times 125 = 5.475$ volts, or say, 5.5 volts. From *l* to *A*, the drop in the two trolley wires will be 33.5 volts. From the station to point *l*, there is a No. 0000 feeder in parallel with two No. 00 trolley wires; hence, the total cross-section of copper is $211{,}600 + 2 \times 133{,}000 = 477{,}600$ circular mils. The drop from the station to point *l* is therefore

$$e = \frac{10.8 \times 6{,}600 \times 125}{477{,}600} = 18.7 \text{ volts, nearly.}$$

The total drop from station to cars is the sum of the drops in the different portions of the circuit, or $5.5 + 33.5 + 18.7 = 57.7$ volts.

If feeders *f*, *f′* were not provided, the drop with five cars bunched at *A* would be $5.5 + 33.5 + 42.1 = 81.1$ volts. Adding feeders *f*, *f′*, therefore, effects a reduction of 23.4

volts in the drop under the most unfavorable conditions. If the load were concentrated at the power-station end of the section, there would be little or no resistance in the circuit, save that of the tap wire and the ground-connection wire, so that it is safe to say that the loss caused by a current of 125 amperes would not at this point be more than 5 volts. The power-house taps, as well as the line feeder, should be provided with feeder switches, so that the current can be cut off at any section desired.

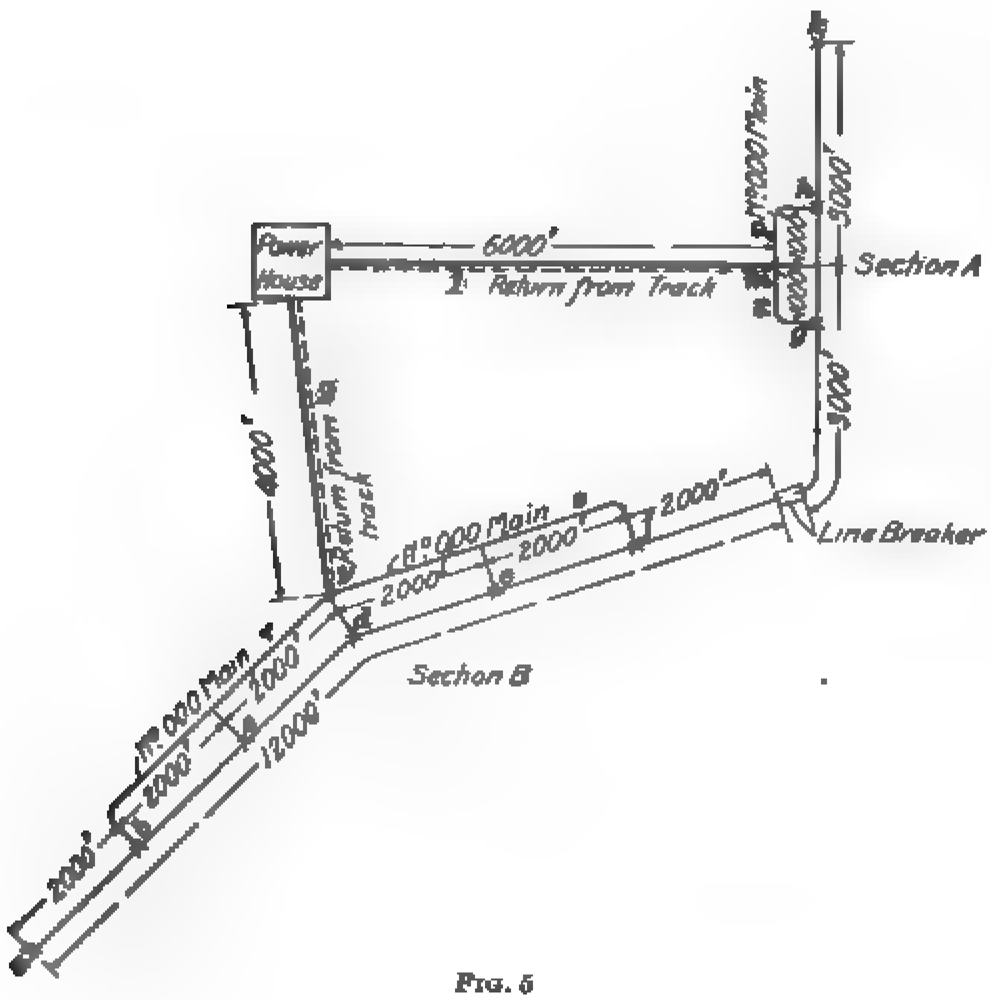



FIG. 5

SMALL ROAD WITH RETURN FEEDERS

**14.** To illustrate the calculations for a road where the power house is not situated alongside the track and where return feeders must be run, the following example will be taken:

EXAMPLE.—Fig. 5 shows the layout of a single-track road operating nine cars, which are spaced fairly evenly along a line divided into two sections by means of a line breaker. The sections are provided with

No. 000 mains, fed by two feeders *1* and *2* running from the power station. Return feeders, represented by the dotted lines, are run alongside the outgoing feeders and the drop under average conditions is to be limited to 50 volts. Each car takes an average current of 25 amperes, the track is laid with 80-pound rails, and the trolley wire is No. 00.

Solution.—Since the cars are equally spaced and constantly shifting in position, the drop will vary somewhat, depending on the position of the cars. In order to make things definite, we will assume that the cars are located as shown by the crosses. This will represent a fair average condition, and the drop for other positions will not be greatly different unless the cars become bunched. If the feeders are designed so that the drop from the power house to cars *a* and *k* will not exceed 50 volts, it is evident that the drop to the other cars will fall under the prescribed 50 volts, because cars *a* and *k* are the most distant from the station. A single track laid with 80-lb. rails has a resistance of .0053 ohm per 1,000 ft., assuming the joints to be perfect; in order to allow for imperfect joints we will take the resistance per 1,000 ft. as .0065 ohm. The conductivity of the copper in the trolley wire may be taken the same as that in the distributing mains and feeders, and it will be sufficiently accurate to take the cross-section of the No. 00 trolley wire as 133,000 cir. mils and the No. 000 mains 167,800 cir. mils. First take section *A* and determine the size of feeder *1*.

*Section A*. The road operates nine cars and is 18,000 ft. in length; hence, there will be one car for every 2,000 ft. Section *A* will have three cars and the current supplied by feeder *1* will be 75 amperes. The sizes of trolley wire and distributing main are fixed so that the drop in these and in the track must first be determined, the remainder will then be the allowable drop in the outgoing and return feeders. The ground return feeder taps in at the center of each section so that for the upper half of section *A* there will be 25 amperes flowing back from *k* through 2,000 ft. of track and 50 amperes back from *h* through 1,000 ft. of track. The drop through the stretch of track *k m* will therefore be $25 \times .0065 \times 2 + 50 \times .0065 \times 1 = .65$ volt. The wire has a cross-section of 133,000 cir. mils, is 2,000 ft. long, and carries 25 amperes; hence, drop $e = \frac{10.8 \times 2{,}000 \times 25}{133{,}000} = 4.06$ volts.

From *m* to *h*, the trolley wire is in parallel with a No. 000 main; hence, the total copper cross section is $133{,}000 + 167{,}800 = 300{,}800$ cir. mils; the current is 50 amperes, and drop $e = \frac{10.8 \times 1{,}000 \times 50}{300{,}800} = 1.79$ volts. The total drop between *m* and *k* and in the track-return circuit will be $.65 + 4.06 + 1.79 = 6.50$ volts, thus leaving $50 - 6.50 = 43.5$ volts for the drop in the outgoing and return feeders.

The current in feeders *1* is 75 amperes, and the total length (outgoing and return) 12,000 feet; hence, circular mils of feeders for section $A = \frac{10.8 \times 12{,}000 \times 75}{43.5} = 223{,}450$, approximately. Either No. 0000 B. & S. wire (211,600 cir. mils) or a 300,000-cir.-mil cable can be used for these feeders, the latter being preferable.

*Section B*.—The drop in the track from *a* to *d* will be $25 \times .0065 \times 2 + 50 \times .0065 \times 2 + 75 \times .0065 \times 2 = 1.95$ volts. In the overhead work, the drop between *a* and *b* in the trolley wire will be the same as from *k* to *h* in section *A*; i. e., 4.06 volts. The drop between *b* and *c* will be twice that between *h* and *m* in section *A* because the current and sizes of wires are the same but the distance is twice as long; hence, the drop from *b* to *c* is $1.79 \times 2 = 3.58$ volts. Car *d* will cause no drop in the track or overhead work because its current is taken directly from the feeder. The drop between *c* and *d* will be that due to 75 amperes through 2,000 ft. of combined trolley and main; hence, drop $e = \frac{10.8 \times 2{,}000 \times 75}{300{,}800} = 5.4$ volts, nearly. The total drop between *a* and *y* is therefore $1.95 + 4.06 + 3.58 + 5.4 = 14.99$, or say, 15 volts, leaving $50 - 15 = 35$ volts for the drop in the outgoing and return feeders. The current in feeders *2* will be that due to six cars, or 150 amperes, and the total length of feed-wire is 8,000 ft.; hence, circular mils of outgoing and return feeders for section $B = \frac{10.8 \times 8{,}000 \times 150}{35} = 370\ 286$. For these feeders 350,000-cir.-mil cable will be suitable.

## CARRYING CAPACITY OF FEEDERS

**15.** In making these calculations, no attention was paid to the carrying capacity of the wires and cables. Of course, this point must be kept in mind, because if the lines are simply figured out on the basis of giving the allowable drop, it might happen that the current would overheat the wires. Table I, due to Mr. H. W. Fisher, gives the approximate amount of current that wires may be allowed to carry without causing the temperature to increase much over 25° F. above that of the surrounding air.

In most cases, however, it will be found that the size of wire needed to keep the drop within the specified limits will be considerably larger than that necessary to carry the current without overheating. Only in cases where the distances are short is there likelihood of the wire not being large enough. It is always well, however, to compare the

TABLE I

CURRENT-CARRYING CAPACITY OF FEEDERS

| No. B. & S. Gauge | Circular Mils | Carrying Capacity, With a Rise in Temperature of 25° F., Approximately Amperes | No. B. & S. Gauge | Circular Mils | Carrying Capacity, With a Rise in Temperature of 25° F., Approximately Amperes |
|---|---|---|---|---|---|
| Stranded Cables | 500,000 | 509 | 2 | 66,370 | 124 |
| | 400,000 | 426 | 3 | 52,630 | 107 |
| | 350,000 | 388 | 4 | 41,740 | 91 |
| | 300,000 | 355 | 5 | 33,100 | 74 |
| | 250,000 | 319 | 6 | 26,250 | 63 |
| 0000 | 211,600 | 275 | 7 | 20,820 | 52 |
| 000 | 167,800 | 237 | 8 | 16,510 | 44 |
| 00 | 133,100 | 195 | 9 | 13,090 | 36 |
| 0 | 105,500 | 168 | 10 | 10,380 | 30 |
| 1 | 83,690 | 143 | | | |

sizes obtained and the current that the wires must carry with the values given in the table. If the wires should prove to be too small, the only thing to do is to use a wire that will carry the current safely or else run the risk of the wire overheating. If the larger wire is used, it will result in a somewhat smaller drop, but this will be an advantage, although the first cost of the wire will be a little higher.

**16. Effects of Low Voltage.**—If the drop becomes excessive, either on account of the feeding system being too light or the load too heavy, it will produce a low voltage at the cars, and this in turn means low speed. It is a well-known fact that just as soon as the voltage on a system becomes low, troubles with the motors and car equipment begin to multiply. There are many cases on record where controller and brush-holder troubles have been very much decreased and where the roasting of field coils, controller blow-out coils, and the throwing of solder out of the commutator

connections have been entirely stopped simply by raising the voltage on the line.

Suppose that a road having a certain number of cars is operated at, say, 550 volts and on a certain schedule; also, suppose that owing to an extension of the road, the addition of more cars, the deterioration of the track-return circuit, or any other reason, the voltage gradually comes down to 400. This will make a maximum decrease of about 20 per cent. in the running speed of the cars. If the time table is rearranged so that the motormen can run the cars on time with the same ease that they could with the higher voltage, the troubles with the rolling stock will not only not increase, but they will actually decrease, because the lower voltage is not as hard on the insulation and arc-breaking devices and the lower speed is not as hard on the car bodies and trucks.

If, on the other hand, no notice is taken of the gradual decrease in the average line voltage and the same time table is kept in force, the following will be the result: Since the maximum running speed of the cars has been cut down, the motorman must make up time wherever he can. Most of this will be made up at starting and getting the car under headway; part of it will also be made up on curves, crossings, and other places where, under ordinary conditions, slow running would be the rule. At starting, the controller is moved around rapidly and the car takes far more current than it should and the excessive current injures the controller, the commutator, and the brushes. The insulation on the fields becomes roasted and troubles of all kinds are liable to occur simply because the equipment has to be abused to make the car run on time.

As a practical instance of the result of low voltage, the following actual case that occurred where two abutting roads used each other's tracks for about $\frac{3}{4}$ mile may be cited. Their trolley wires were separated by a line breaker and each road had its own feeder system. On o[illegible] of the breaker the voltage was 425 volts; on the oth[illegible] volts. As long as each ro[illegible] only its ow[illegible] the

high-voltage road had no trouble to speak of. As soon as its cars began to run over the low-voltage road, controller and brush-holder breakdowns set in and continued until two extra feeders were run to the low-voltage side.

The above effects have been noted here simply to show that the question of proper voltage is an important one. It is true that there are many roads operating under an excessive drop, and this in itself is not so bad if the pressure at the station is increased so that the proper voltage at the cars is maintained. At the same time, a large drop means a large waste of power, and the question as to whether it will pay better to lose a considerable amount of power or buy more feed-wire is something that must be determined by the relative cost of power and copper.

## ELECTROLYSIS

**17. Introductory Remarks.**—The subject of **electrolysis**, by which is here meant the eating away of the rails, underground pipes, or other buried metallic conductors by stray currents from the street-railway system, is closely connected with the feeding system, especially with the track-return part of it. When electrolysis was first noticed, a great outcry was raised against the trolley roads by gas and water companies, telephone companies, and other corporations owning underground pipes or lead-covered cables. The many lawsuits brought against electric-railway companies led to an investigation of the subject, with the result that electrolysis is not feared nearly as much as it once was, because means have been devised for avoiding it largely or for limiting it to sections where it can be watched or provision made to prevent it.

**18. Elementary Principles.**—In Fig. 6, *A* and *B* are two iron plates buried a short distance apart in damp earth. If the terminals of *A* and *B* are connected to a dynamo and a current made to flow from *A* to *B* through the earth, plate *A* will be eaten away or pitted while plate *B* will not

be damaged. This is practically the same electrochemical effect that takes place in electroplating, where metal is taken from a plate, or anode, and deposited on the article to be plated. The point to notice is that wherever current flows *from* a metal conductor into damp earth, the conductor is eaten away, provided that the difference of potential between the conductor and the adjacent earth is sufficient to effect the chemical decompositions; but where current flows from the earth *into* the conductor, the latter is not damaged. The rate at which the metal will be eaten depends on the strength of the current.

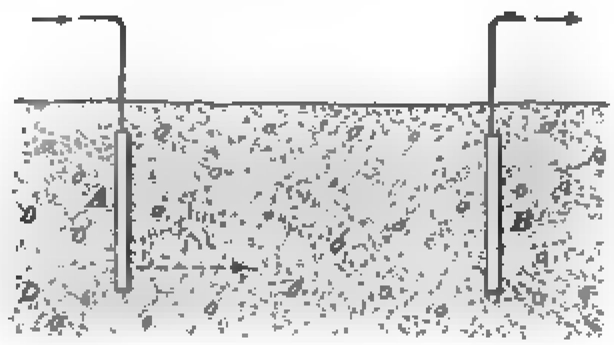


FIG. 6

**19.** Table II shows the weight of metal that will, theoretically, be eaten away by 1 ampere flowing steadily for 1 year, for metals likely to be affected by stray underground currents.

TABLE II

ELECTROLYTIC EFFECT OF CURRENT ON VARIOUS METALS

| Metal | Grams per Ampere-Hour | Pounds per Ampere per Year |
|---|---|---|
| Aluminum | .327 | 6.31 |
| Copper | 1.190 | 22.97 |
| Iron | 1.044 | 20.15 |
| Lead | 3.852 | 74.34 |
| Tin | 2.218 | 42.71 |
| Zinc | 1.216 | 23.47 |

This table is of interest chiefly because it shows the relative effect of a current on the different metals. It does not follow that in practice, whenever a current of 1 ampere flows

for 1 year from a conductor into the ground, the amounts of metal indicated by the table will be eaten away. In fact, under some circumstances current may flow from a buried conductor to the ground without eating the metal at all. For example, the ions liberated by the current may be such that no corroding action takes place on the pipe, or the energy expended per unit area of the pipe surface may not be great enough to decompose the salts in the damp earth. It has also been found in many cases that electrolytic action may take place for a while and then cease owing to the character of the earth around the conductor having become changed by the decomposition of the salts contained therein and rendered incapable of acting as an electrolyte for further electrolytic action. It should also be remembered that underground pipes and conductors may become corroded by the simple chemical action of the salts contained in the earth, and whenever a conductor or pipe shows signs of pitting it by no means follows that the corrosion is due to electrolysis; in fact, there is no sure way of telling simply from the appearance of the pipe to which source the corrosion is due.

Mr. Albert B. Herrick* suggests the following method for determining definitely whether or not corrosion is due to simple chemical action or to electrolytic action. The pipe in question is uncovered for about 8 feet of its length. Half-round test shields made of material as nearly like the pipe as possible and of inside diameter corresponding with the outside diameter of the pipe, are provided; the length of these is usually about three times the diameter of the pipe to be tested. A length of the pipe corresponding to the length of shield is carefully cleaned and amalgamated, and the inside surfaces of a pair of shields are similarly treated. The shields are then firmly fastened to the pipe by bolting the semicircular halves together by means of bolts passing through projecting flanges. Another pair of plates is also bolted to the pipe, alongside of but not touching the first

*Street Railway Journal, Vol. XXIII, No. 14.

pair, and before bolting them in place the pipe is covered with a ⅛-inch sheet of rubber. The second sheath is thus insulated from the pipe while the first is in good metallic contact with it and before being placed in position both shields are carefully weighed and notes made as to the character of their surfaces. The pipe and sheaths are then covered with earth and allowed to stand undisturbed for 6 months. At the end of that time they are examined, carefully cleaned, and weighed. If the insulated shield has been corroded it must have been on account of ordinary chemical action and the difference in weights will indicate the amount of corrosion. If the uninsulated sheath is corroded it may be due to electrolytic action, to ordinary chemical action, or to a combination of the two. By thus noting the difference in the effects on the two shields, the effects of corrosion from the two sources can be determined.

In Table II, it is interesting to note that lead is eaten away more rapidly than any of the other metals there given. Underground lead pipe, and the lead sheaths of underground cables are, under like conditions, eaten away much more rapidly than iron pipe. Also, wrought-iron pipe is much more susceptible to electrolytic corrosion than cast-iron; with cast iron the impurities in the iron appear to form a kind of scale that protects the pipe.

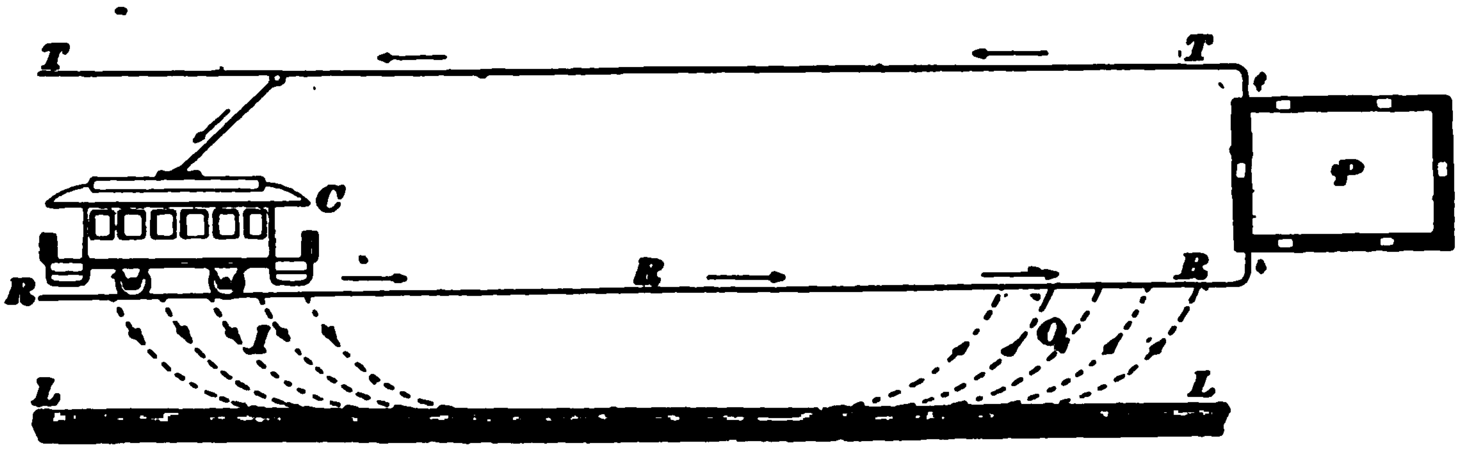



FIG. 7

**20. Electrolysis Due to Railway Currents.**—Fig. 7 gives a simple illustration as to how electrolysis may occur in connection with an overhead-trolley system. *T T* is the trolley wire and *R R* the track; under ordinary conditions, the current returns by way of the rail, as indicated by the

arrows. If, however, there happens to be a pipe $L$ $L$, in the neighborhood of the track, that offers a ready path for the current, part of the current will leave the rails, as at $I$, enter the pipe, and flow out again at $O$ to return to the power station. At $O$, where the current leaves the pipe, electrolytic action will be set up, if the conditions are favorable, and in the course of time will eat holes in the pipe. At $I$, the current leaves the

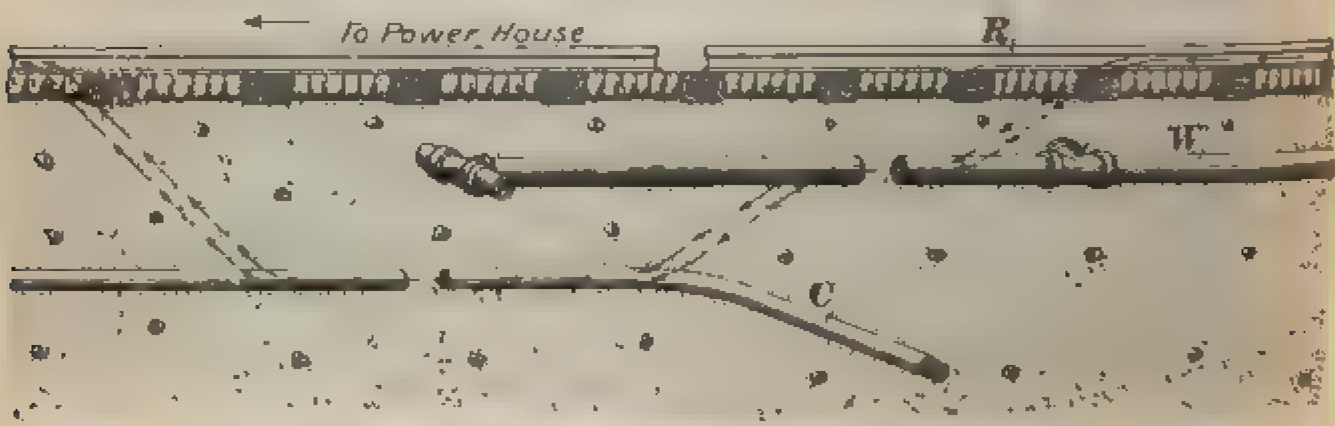



FIG. 8

rails; hence they will be eaten away to some extent. If the trolley wire were connected to the negative pole of the dynamo instead of the positive, the current would flow out through the track, and whatever corrosion occurred on the pipes would take place at points removed from the station and would be scattered over a wide area. On the other


FIG. 9

hand, with the positive pole connected to the trolley, whatever action takes place on the pipes is confined to districts near the power house. These areas are comparatively small, and measures can be taken to protect them. This is the principal reason why the positive pole of the dynamo should be connected to the trolley side of the line. Figs. 8 and 9 show modifications of the simple case shown in Fig. 7.

In Fig. 8 the current leaves the rail *R*, enters the pipe *W*, and flows through *W* until a better path presents itself in the shape of the lead-sheathed cable *C*. It flows along *C* until the track presents a better path, when it flows back to the rail again, as indicated by the arrows. Electrolytic action may occur where the current leaves the rail, the iron pipe, and the lead sheath of the cable. Fig. 9 shows a case where a cable and pipe run parallel to the iron rail *A B*, the arrows indicating the path of the stray current. Lead-covered underground cables are particularly liable to damage, because lead is eaten away much more rapidly than iron; moreover, the corrosion never takes place evenly, but in spots, so that the pipe or sheath becomes pitted and is soon destroyed. However, the general practice now is to run underground cables in tile ducts which form an insulating medium between the cable sheath and ground, thus preventing electrolysis to a large degree. Wrought-iron pipes are more quickly eaten than cast-iron; in fact, the harder grades of cast iron, such as chilled iron, seem to be very little affected.

It is seen, by referring to Fig. 7, that if the track return is in good condition, there will be little inducement for the current to leave the track and pass through the intervening earth to come back on the pipes. One of the most effective precautions against electrolysis is thorough rail bonding. With the greater attention that is paid to rail bonding on modern roads, there has been a corresponding reduction in the damage due to electrolysis.

**21. Testing for Electrolysis.**—The difference of potential between a pipe and the track depends on the current flowing between the two and the resistance of the intervening earth. The difference of potential that is effective in producing electrolytic action is that which exists between a pipe and the earth immediately surrounding the pipe. A very small E. M. F. may be sufficient to cause electrolysis while the E. M. F. measured between pipe and track might be quite high because of the intervening resistance. In order for electrolysis to take place, the pipe must be positive to

the surrounding earth so that current will flow from the pipe to the earth. If a test shows that the earth is positive to the pipe there is no danger at that point so far as the pipe is concerned. The old method of testing between the pipe and rail with a millivoltmeter does not give reliable information as to the potential between the pipe and adjacent earth, and

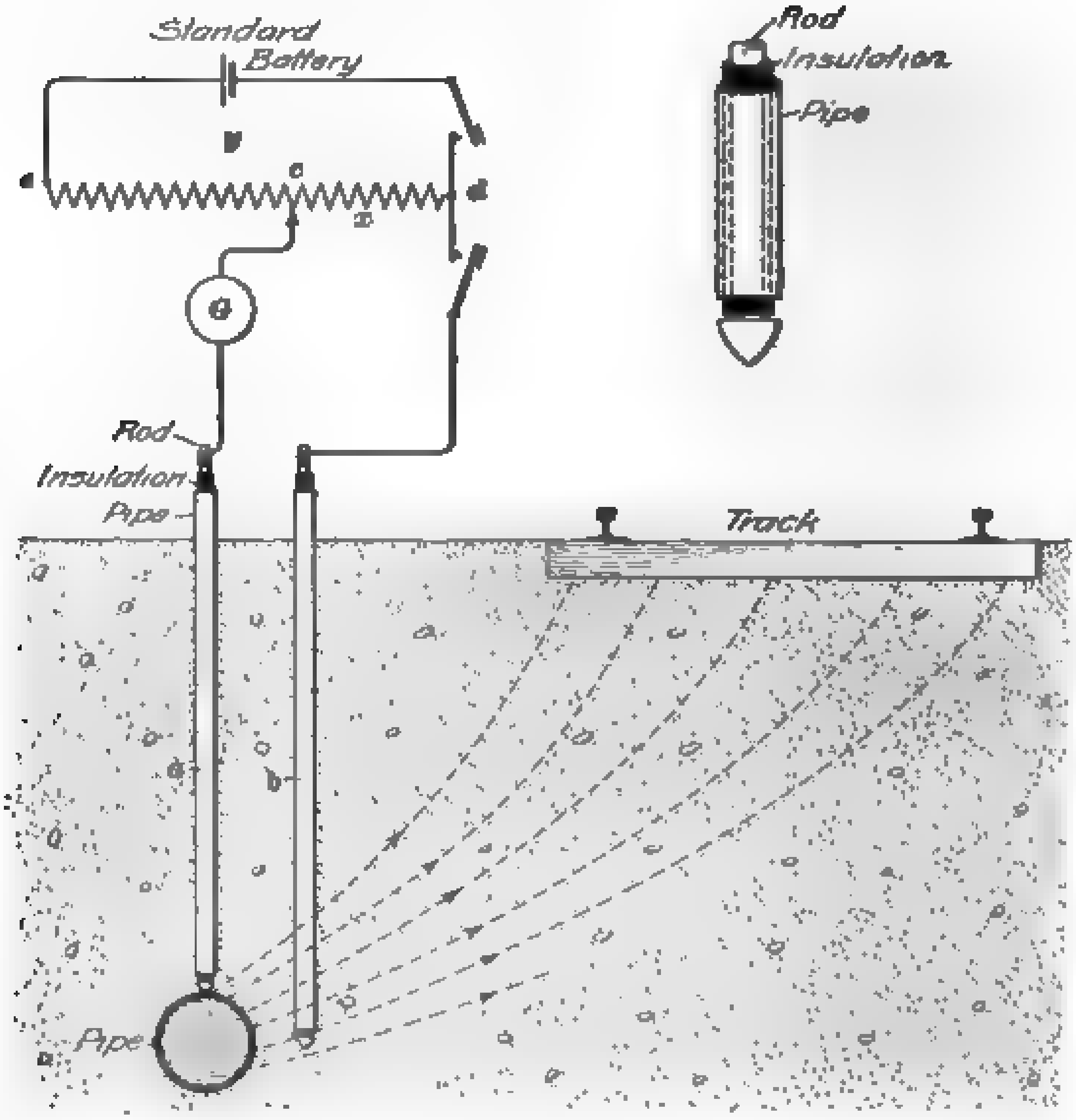



FIG. 10

the following test is recommended by Mr. Herrick as being much more reliable. An insulated pointed rod *a*, Fig. 10, is driven through the soil until the point comes in contact with the pipe. A second insulated rod *b* is driven in so that its point will come close to the pipe but will not touch it. Both rods are insulated and protected by running them through a piece of iron pipe lined with insulating material, as, for

example, a piece of lined conduit such as is used for wiring buildings. The earth potential point is covered with cadmium so that there will not be a local E. M. F. set up, which will disturb the difference of potential due to the earth currents. Also, the E. M. F. existing between the pipe and the test point is measured not by means of a voltmeter, which would disturb the normal current flowing between pipe and ground, but by balancing the unknown E. M. F. against a known E. M. F. from a standard battery. The resistance $c$ is adjusted until the galvanometer indicates zero current, and the E. M. F. between pipe and ground then bears the same relation to the known E. M. F. of the standard battery that resistance $x$ between $c$ and $d$ bears to the total resistance $y$ included between $e$ and $d$; or,

$$E_1 = E\frac{x}{y} \qquad (3)$$

where $E_1$ = E. M. F. between pipe and ground;
$E$ = E. M. F. of standard battery;
$x$ = resistance $c\,d$;
$y$ = total resistance.

It is not necessary to know the values of $x$ and $y$, in ohms; if the ratio of their resistances is known it is sufficient. Resistance $y$ can be in the form of a bare high-resistance wire wound on a cylinder and provided with a sliding contact and scale, so that the divisions read off for any position of the contact will be proportional to the resistance $x$.

EXAMPLE.—A test was made, as shown in Fig. 10, with a standard battery giving 5 volts and a sliding contact resistance divided into 100 equal parts. When the galvanometer gave no deflection, resistance $x$ was represented by 30 divisions on the scale. What was the E. M. F. between the pipe and ground?

SOLUTION.—In formula 3, since the resistances are proportional to the lengths of wire,

$$\frac{x}{y} = \frac{30}{100} \text{ and } E_1 = 5 \times \frac{30}{100} = 1.5 \text{ volts. Ans.}$$

**22. Prevention of Electrolysis.**—A large system of piping forms a conducting network of very low resistance in

parallel with the track, hence it is a very difficult matter to prevent part of the current from leaving the track. However, if proper steps are taken, the bad effects of electrolysis can be largely avoided; the following are the main points that experience has shown should be observed:

(*a*) The trolley wire should be made the positive side of the system.

(*b*) The track should be thoroughly bonded and the bonds maintained in good condition.

(*c*) Any metallic connections that may exist between piping or cable systems and the track should be located and removed.

(*d*) Return feeders should be run out from the station and connected to those pipes that carry the greater part of the current. Thus, the current in the pipes will be "drained" off without passing from the pipes to ground.

(*e*) Where service pipes, cables, or underground conductors pass under tracks or through other regions where they are exposed to electrolytic action, they can often be protected by covering them with glazed tile or by placing them in a trough filled with asphalt.

(*f*) If in any part of a system the rail return carries an excessive current, return feeders should be run so as to relieve the rail of part of the current and prevent an excessive fall of potential along the rail. The greater the fall of potential in the rails the greater is the tendency for the current to pass off to neighboring pipes.

The remedy given under (*c*) is important. Very often accidental connections exist between the rails and pipe so that current can pass directly to the piping system. This is specially the case where pipes run across iron bridges that also carry railway tracks. Before attempting to "drain off" the current from a piping system it is needless to say that all metallic connections between track and pipe must be removed. Where pipes pass across iron bridges the best plan is to insulate the pipe from the bridge, or if this is impossible, insulate the pipe by the insertion of insulating joints at either end of the bridge.

Remedy (*d*) is very commonly practiced and gives good results if properly applied. The return feeders should be attached to the pipes that carry the most current and, as a rule, the current so returned to the power house will not be more than 5 or 6 per cent. of the total current; if it exceeds this amount it is probable that there is a metallic connection somewhere between the track and pipes.

Service pipes crossing under street-car tracks are particularly subject to electrolytic action, and when they are being laid or repaired it costs but little to cover them with tile or to run them in a box, as explained in (*e*).

**23. Method of Measuring Current in Pipe.**—Fig. 11 shows a convenient method for measuring the current flowing in a pipe. Clamp terminals *a*, *b* are attached from 4 to 6 feet apart, and low-resistance connections made to an ammeter *c* through a switch *d*. A millivoltmeter *e* is also connected across the terminals, and readings taken from it with the switch *d* open and with *d* closed. The reading of the ammeter is also noted when the switch is closed. The current flowing in the pipe is then obtained from the formula

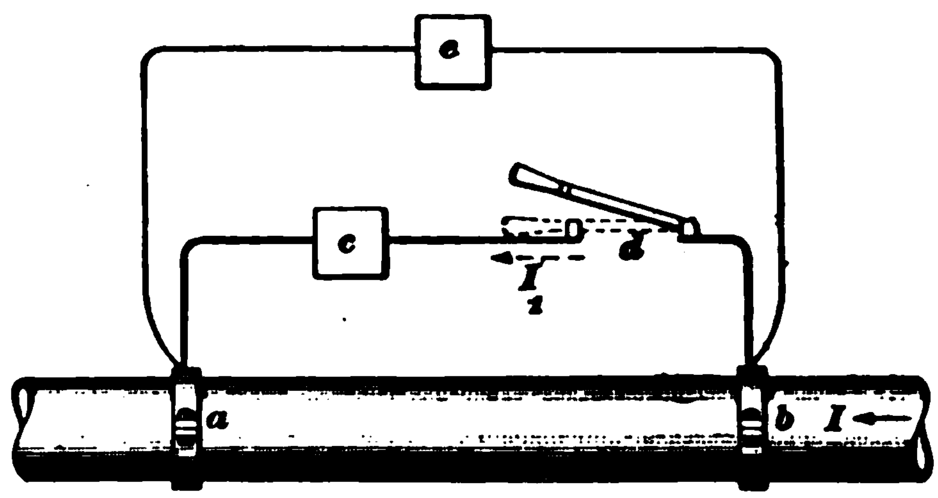


FIG. 11

$$I = \frac{I_1 E}{E - E_1} \qquad (4)$$

where $I$ = amperes in main pipe;
$I_1$ = amperes indicated by ammeter *c* when switch *d* is closed;
$E$ = volts indicated with switch *d* open;
$E_1$ = volts indicated with switch *d* closed.

EXAMPLE.—In Fig. 11, the current indicated by *c* with *d* closed is 20 amperes and the reading of *e* is 300 millivolts. With *d* open, *e* reads 400 millivolts. How many amperes are flowing in the pipe?

SOLUTION.—In formula 4, $I_1 = 20$, $E = 400$ millivolts $= .4$ volt, $E_1 = 300$ millivolts $= .3$ volt; hence,

$$I = \frac{20 \times .4}{.4 - .3} = 80 \text{ amperes. Ans.}$$

**24. Systems Free From Electrolysis.**—Systems using the double overhead-trolley or conduit system where the rails do not form the return circuit, are, of course, free from trouble due to electrolysis. Also roads where alternating current is supplied to the cars are exempt because alternating current, even if it does return by way of pipes, is incapable of producing any electrolytic effect.

## AUXILIARY EQUIPMENT

**25.** The part of an electric-railway system that pertains directly to the supply of current for the cars has been taken up, but the rolling stock and car equipment remain to be considered. Before going on to this part of the subject, it may be well to pay some attention to the auxiliary departments of a road. Under this head may be included car houses or car barns, repair shops, etc. These, while not, perhaps, directly connected with the running of the cars, are at the same time an essential part of the road. Their equipment varies greatly on different roads, so that the descriptions can only be very general in character.

### THE CAR HOUSE

**26.** The **car house** or **car barn** is a building used for storing cars that are not in use. It is now customary to provide storage under cover only for those cars that are not in regular commission. Cars that are running regularly are stored outdoors; there is no good reason why a car that is in fit condition to be out all day in all kinds of weather should be put under cover over night, especially when such storage room is expensive and when there is always more or less danger from fire.

Where practicable, the tracks in car barns should be far enough apart to admit of easy passage between them, and the more uniformly the daylight is diffused throughout the building, the better. In some car houses, the storage room is all on one floor; this may be the first or second floor, according as the cars to be stored are out of season or are just temporarily out of use. In other storage houses, two or more floors are used, in which case an elevator must be provided for handling the cars on the upper floors.

Where the cars must be transmitted to and from an upper story by means of an elevator, it is almost always the case that the stripped or out-of-season cars are stored there. As there is no possible chance of saving the cars in time of fire, there is no objection to setting them on horses or barrels; but where the storage tracks are on a level with a street track, the cars should be set on temporary trucks, so that at an alarm of fire they can be run out. Where practicable, every storage track should lead to the street at one end or the other of the car house. In some houses it is the practice to grade the rails down to the street, so that in case of fire it is only necessary to let off the brakes and the cars will run out.

**27.** For inspection of trucks and motors there should be **pits** about 4 feet 8 inches deep directly under the tracks, no pit to be shorter than any car that may be placed over it. As to the total amount of pit room required per car, it is a very hard matter to fix between narrow limits, as it depends a great deal on how much trouble the equipments give. A safe value, however, based on long experience with almost all conditions of working with several types of motors and trucks, is 1 linear foot of pit room for each car that runs into the depot; though in some modern car barns the allowance is much less than this for the reason that it is now considered best to remove the car bodies from the trucks and work on the motors from above when thorough overhauling is required. Pits are used for ordinary inspection or for light repairs, but when an equipment has to be thoroughly gone

over a much better job can be done by dispensing with pit work altogether. The pits should have cement bottoms and be properly drained. The space between the tracks on the floor level should be boarded, but the underneath space between the pits should be left open.

A couple of shelves and a row of small bins to hold a few of the most commonly used sizes of bolts, nuts, and washers save time and should be placed in each pit.

**28. Wiring of Car House.**—The wiring of the car house is a simple matter, but its plan depends on the track layout of the house. Every track should have a trolley wire over it. The house trolley wiring, as a whole, should be separated from the main line outside by means of a line circuit-breaker; it must then be connected to the street wires by means of a jumper that passes through a switch placed outside of the building, so that in case of fire the whole house wiring can be disconnected. The wires in the house are supported on barn hangers (see Fig. 12). The hanger is fastened to the house beam by means of lugs *b*, *b*, the trolley wire being fastened to ear *c*; in barns with steel roof trusses, the hanger must be screwed to wooden blocks supported from the iron girders. In some barns, the trolley wire is run in an inverted wooden trough, the hangers being screwed to the bottom of the trough. In such a case, the trough generally catches the wheel if for any reason it leaves the wire; it also serves as an insulated support for the wheel at night and obviates the necessity of tying down the pole where such a rule is in force. Sometimes at short curves under very low structures it is the practice to do away with the trolley wire altogether and replace it with an inverted brass or copper trough, in which the trolley wheel rolls along on its flanges.

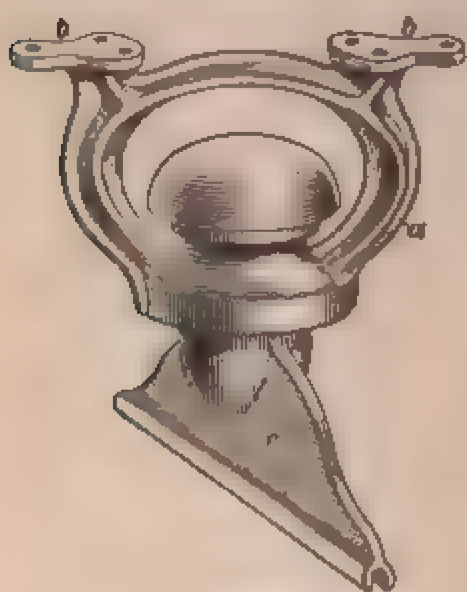



Fig. 12

## THE REPAIR SHOP

**29.** The **repair shop** is the place where all heavy repairs and alterations are made. A well-appointed repair shop should include a machine shop, carpenter shop, mill, blacksmith shop, paint shop, winding room, commutator room, controller room, and a wheel-grinding annex. In the machine shop, all general machine work is done, such as fitting bearings, turning down commutators on the shaft, recutting bolts, etc. In the winding room, fields, armatures, armature coils, etc. are wound, insulated, and baked. In the commutator room, the parts of the commutator are assembled and the finished article tested. In the controller room, controllers, switches, resistances, etc. are repaired, and in the mill, the repair parts for car bodies are made. The shop building should be a substantial fireproof structure and every effort should be made to have good light throughout.

**30. The Pit Room and Machine Shop.**—The number and length of the pits depend on the nature of the work to be done and the number of cars to be handled. The pit rails should be laid on stringers supported by brick piers, and the space underneath between pits should be left open, so that a man can go from one pit to another without going up on the floor. There should be means provided for raising the car bodies off the trucks quickly and with as little labor as possible. It is common practice to provide car shops with an air compressor and reservoir, the air to be used in blowing the dust out of motors, controllers, etc.; in such a case, the compressor, or air pump, is driven by a motor. The air pump stores the air in a main reservoir that is piped to auxiliary reservoirs situated at the points where the air is to be used. Air has proved to be the best thing for cleaning purposes, and in the several instances where it has been used as a means of operating lifts to raise cars and to handle heavy work around the lathe and boring machines, it has scored an equal success.

**31. The Machine Shop.**—In laying out a machine shop, two important points must be kept in mind: the machines

must be so disposed as to admit of having a good light thrown on the work and at the same time must take up as little floor space as possible. The number and kind of machines to be installed depend on the class of work to be done. There should be enough machines so that the work may not be held back for want of them, but at the same time there should be no more of the same or similar kinds than can be kept busy.

The machines necessary are about as follows: One lathe to take an axle with the wheels on it; one smaller one to take armatures and bearings; one speed lathe; one metal saw; one large and one small drill press; one boring mill; one planer and shaper; one bolt-cutting machine, with right- and left-hand dies; one milling machine; one wheel press; one axle straightener; emery wheels, one grindstone; one power hack saw; one ratchet drill, one punch press; and one power hammer, usually in the blacksmith shop. On a small road, some of the above might be omitted.

**32. The Winding Room.** As good a place as any for a winding room is in a gallery built around the wall above the machine shop, but a great many object to this plan on the ground that all cores to be wound and wires for winding must be elevated to the gallery. This is true; and where there is plenty of room on the ground floor, it is best to do the winding there, but where space is limited, the above location is a good one. The size of the armature room required for a given number of cars depends, of course, on many local conditions. For a road operating 100 cars or over, from 6 to 8 square feet of floor space per car should be sufficient. For a small road, the space required per car would be much larger. Every winding room in which all the processes of winding are carried out and where coils are not bought ready-made, should be equipped with about the following: One machine for putting bands on armatures, one field-winding machine; one armature-coil winding machine with a coil former for each type of armature; one gasoline stove, brick-enclosed, with the tank well removed and

enclosed (gas is better and safer when it can be had) for heating soldering irons; a device for pulling off commutators (the pinions should be removed before the armatures are sent in); racks for holding rolls of insulation; stands for holding armatures in course of winding; one machine for cutting insulation; one machine for pressing coil papers; one coil press for each kind of coil; ample facilities for dipping the coils in varnish or some other compound; racks for holding completed armatures; an oven or its equivalent for baking armatures (it can be either steam-heated or heated with street-car heaters). If the armature coils are dipped in an air-drying compound, no oven is needed, because the armatures themselves and the fields and other coils can be baked by sending a current through them; but if the armature coils are to be dipped in varnish—a much better practice—an oven must be provided, and it might just as well be large enough to bake everything.

The winding room should be provided with substantial patterns of every standard piece of insulation used in the place; one set of these should be hung in a convenient place; a duplicate set should be kept under lock and key, preferably in a fireproof place.

**33. The Commutator Room.**—The commutator room should be in charge of a good mechanic, and should contain a lathe, a drill press, a milling machine, and an oven for baking commutators. It should be provided with a full line of gauges for the several kinds of mica bodies used and plug gauges for the shaft hole bored in the shell. There should be provided a device for tightening up the nuts without twisting the commutator bars out of line. There must be an adequate supply of assembling rings and the proper wrenches for adjusting them; no emery wheel should be allowed in the commutator room. The most natural and convenient location for the room is next the winding room; it should be enclosed, but should have the best possible light and ventilation.

**34. The Controller Room.**—There is no particular condition to be fulfilled in selecting a site for the controller

room. A location just off the machine shop, where it will be convenient to the machines, is as good as any.

**35. The Mill and Carpenter Shop.**—The mill is the room in which the wood-working machines are placed and the carpenter shop is where the cars are run in for general body repairs. There is no reason why they should not both be within the same enclosure—the mill at one end and the carpenter shop at the other. The best place for them is between the machine shop, pit room, and paint shop, a line of single or double track running through, so that a car can come in at one end of the building and go out at the other. In the mill there should be a planer, boring machine, lathe, band saw, circular saw, and grindstone.

**36. The Paint Shop.**—The paint shop should be at the extreme rear of the main shop and should have free access to the street; it should be provided with as many doors on the street side as there are tracks, so that in case of fire the cars can be run out without any shifting or transferring. The paint shop should receive only cars that have been repaired and are ready to run on the road except for the painting. This being the case, each track in the shop should have a trolley wire over it, the whole system of trolley wires being kept cut out by means of a switch except when they are to be used. Under no circumstances should the car bodies be set on horses or barrels in the paint shop; the risk of fire is too great. They should always be on temporary trucks, and where possible, at the head of each line of cars should be a car fully equipped, so that in case of fire they can be coupled together and towed out of danger. Another good plan is to have the tracks down grade out of the house, so that when the brakes are released or the chocks removed from the wheels, the cars will run out by gravity. On account of the great fire risk incidental to the storage of so many inflammable materials, oils, varnishes, etc., there should be an absolutely fireproof wall between the paint room and the rest of the shop, communication between the two shops being only through self-closing fireproof

doors. As a prime precaution against fire, the building should be of brick, with a fireproof roof and a cement floor. The floor should be graded to gratings that lead to the sewer or to a cesspool and the roof should be designed to give the best possible light and ventilation. All inflammable materials should be kept in a small, absolutely fireproof room that will admit barrels, etc., without trucking them the entire length of the paint shop. The question of fire risk in a paint shop is a serious one, for the reason that the shop is generally full of cars that will burn quickly if once started.

**37. The Blacksmith Shop.**—The blacksmith shop must be located where the coal dust and gases from the forges cannot reach the paint shop. It should contain at least two forges, anvils, and a blower. One forge should be provided with an ordinary bellows all ready to be connected on, in case anything should happen to the blower or to the motor from which it is run. Besides the usual complement of forge tools, there should be a machine hammer, shears, and a drill press.

**38. The Grinding Room.**—If the brakes on a trolley car are applied too hard or if for any other reason the car skids along the track, flat spots, or **flats**, as they are called, are found on the tread of the wheel. These make the wheels pound on the rails, and unless they are removed by grinding or a new wheel put on, the trouble is liable to go from bad to worse. Most car wheels are of chilled cast iron. In the molding, the tread of the wheel is chilled so that the iron is very hard for a depth of $\frac{3}{8}$ or $\frac{1}{2}$ inch. If the wheel is worn down so that the chilled portion is ground through, there is no use in doing anything further with it, as the iron under the chilled part is too soft to last any length of time. If small flats develop, they can often be removed before they get any worse by taking off the regular brake shoe and putting on a special wheel-truing shoe provided with emery, carborundum, or similar abrasive. Fig. 13 shows one of these shoes; it simply replaces the

regular brake shoe and in the course of a few hours' run the abrasive blocks *a* grind the wheel true. When the flat is a bad one, it is removed by a regular grinder, which is a device for holding a revolving emery wheel against the tread of the wheel to be ground. The wheels may be ground either in place on the car or separate from the car. The car-wheel grinder can, as a rule, be used to greater advantage out at one of the depots, if the wheels are to be ground on the car; this is undoubtedly the best practice, but it is not always followed. Where the wheels are taken out to be ground, there must be extra means provided for driving the axle, whereas, if ground on the car, one of the car motors can do the work. In either case, the car wheels should make from 20 to 40 revolutions per minute, and the speed of the rim of the emery wheels should be about 5,000 feet per minute. Steel-tired wheels are trued up by turning in a lathe.

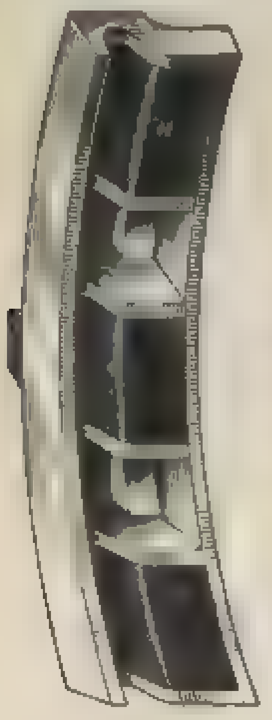


FIG. 13

## CAR BODIES AND TRUCKS

### CAR BODIES

**39.** The **car body** constitutes the main part of the car and is mounted either on one or two trucks, depending on its length. Car bodies are made in a large variety of styles, some being open for summer use, others closed, and others a combination of the two. They are made in lengths ranging from 18 or 20 feet to 40 or 50 feet; the larger cars usually have two rows of seats arranged crosswise as in an ordinary steam railway coach.

**40. Selection of Car Body.**—The selection of the cars for any given road is a matter that requires careful attention No fixed rules can be laid down to govern the selection of the car body in all cases, because conditions vary and a body

adapted to one place and condition of service might fail entirely to meet the requirements elsewhere. In some places, open cars can be used the year round, while in other sections there are only a few days in the year when closed cars are uncomfortable. The average conditions call for both open and closed cars, and much attention has been paid to the question of devising a car that can be made open in warm weather and closed in cold weather. One result of this has been the so-called *semiconvertible* car, a type which all car manufacturers now make. The nearest approach to a solution of the problem of producing a combination car that is as good in hot as in cold weather is found in the car that is partly open and partly closed. This car has the advantage that it is not only adapted to hot and cold weather, but to rainy weather as well. It has the disadvantage that in no kind of weather does it, as a rule, carry a full load, except during the rush hours, so the power house must carry just so much dead weight over the road. Semiconvertible cars are made in a number of different ways, but the windows are made larger than ordinary. In one style of car both upper and lower window sash can be pushed up into pockets in the roof and held there, thus leaving practically the whole side of the car open. In another type no window sashes are provided at all; the windows are of large heavy glass panes fixed in place but arranged so that they can be removed in summer, thus leaving the side of the car open. Of course, in both cases, entrance must be from the ends, hence these cars cannot load or unload as quickly as a regular open car; at the same time they avoid the necessity of keeping two kinds of cars on hand and have come into very extensive use.

The single-truck four-wheel car is giving way to double-truck eight-wheelers, because a single truck, on account of the limited wheel base, cannot well accommodate a car body over 20 or 22 feet long The most economical practice from the energy point of view, is to run **trailers**, which are cars simil [illegible] motor cars, but lighter and not equipped with [illegible] he trailer being so light, the ratio

of live weight to total weight carried is very much increased; also, the trailers can be left off when they are not needed. But unfortunately the use of trailers increases the number of accidents and consequent damage suits, and these more than offset the value of the power saved.

The point must often be decided as to whether single-truck or double-truck cars should be purchased for a road. It can be safely said that if there is the least doubt as to which to buy, give the preference to the double-truck car. There is nothing so attractive as a well-built and well-appointed double-truck car. This type of car is easier on the car body, easier on the line work, easier on the track, and last, but not least, it is easier on the passengers. Actual statistics show that the introduction of the double-truck car will create travel. Being higher from the rail and longer than the single-truck car, it takes longer to load and to unload passengers, and for this reason is not adapted to local runs, where the travel is heavy and the stops frequent. This, of course, does not apply to open cars, where ingress and egress are just as free as on a single-truck car.

## TRUCKS

**41.** The main requirements of a good truck are that it be easy riding, durable, have few parts, wearing parts easily replaced, and wheels easily changed. The trucks must be entirely self-contained; that is, one framework must include the wheels and axles, the brakes, motors and driving gear. This in reality constitutes the car, for the car body above is merely a framework to hold and shelter passengers, having none of the vital parts necessary to operation. The fact must not be overlooked, however, that the car body has to stand severe strains on account of the rapid acceleration at starting and an equally heavy strain when the brakes are suddenly applied in stopping; so that this portion of the car must be carefully designed or it will not last long.

**42. Classes of Trucks.**—Trucks are of two kinds: **single trucks** and **double trucks**; the latter may be

further subdivided into *ordinary double trucks* and *maximum-traction trucks*. A single truck has four wheels, takes a single motor on each axle, and there is one truck to a car; an ordinary double truck has four wheels, all the same size, can take a motor on each axle, and there are two trucks to a car; a maximum-traction truck has two large wheels and two small ones, the idea being to throw most of the weight on the large wheels, which are driven by the motor. The weight on the small wheels is regulated by means of a compression bolt and spring, just enough compression being put on to keep the small wheels on the rail when rounding curves. As a rule, the large wheels take about 70 per cent. and the small ones 30 per cent. of the total weight. Experiment has shown that for a given weight of car, the maximum-traction trucks do not require as large an expenditure of energy as a single truck with a 7-foot wheel base. The single truck, being more rigid, binds more in curves and does not equalize as readily as the maximum-traction truck, with its shorter wheel base. Nevertheless, the maximum-traction truck does not ride as easily as the ordinary truck and is now used comparatively little. The ordinary double truck equipped with a single motor has the disadvantage that the driving power is all on one axle, while the weight is divided between two. The result is a tendency for the driving wheels to spin when called on to do heavy duty, because the traction between the wheel and rail is not great enough. By putting a motor on each axle, making four motors to the car, conditions are much improved.

For large interurban cars, ordinary double trucks are always used, but they must be of heavier construction than for the lighter cars used for city traffic. In many cases, one of the trucks is made especially heavy and both motors placed on it, the other truck being without motors. In some cases, however, where the cars must have a very powerful motor equipment, it has been found advisable to use four motors, one on each axle, because the space is so limited that it is sometimes difficult to develop the necessary power in two motors without overheating.

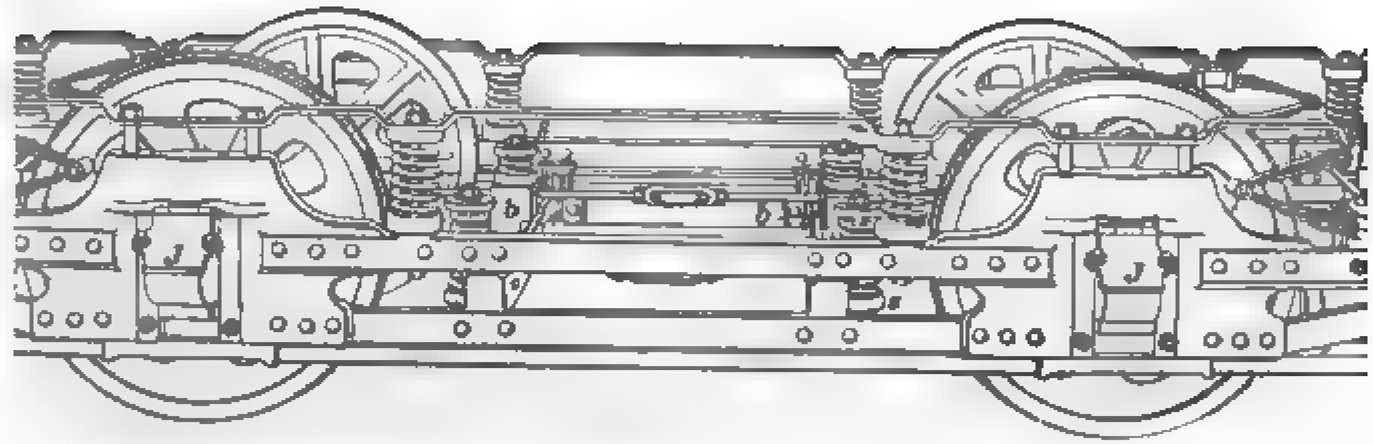


FIG. 14

The car body is rigidly bolted to a single truck by body bolts passing through the car sills and the top rail of the truck's side frame. Double trucks are attached to the car body by means of center bearings and pins, around which the truck turns as a center. Part of the weight is sustained and the car body kept balanced by the **rub plates**, which are circular pieces that engage mates attached to the car body; they should be kept well greased. Cars mounted on double trucks sit higher from the rail than single-truck cars, because the body of the car has to clear the wheels and motors. In open cars the truck wheels have to clear the side steps, so that in some cases two steps must be used.

**43. Types of Trucks.**—Fig. 14 shows a type of single truck; Fig. 15, an ordinary double truck; Fig. 16, a maximum-traction truck. In Fig. 14, the motors are supported by the suspension bars *b*, *b*, which are in turn carried by the springs *s*, *s* resting on the side frame of the truck. Since it is advisable to support the motor on springs, it is, of course, equally necessary to provide a flexible support for

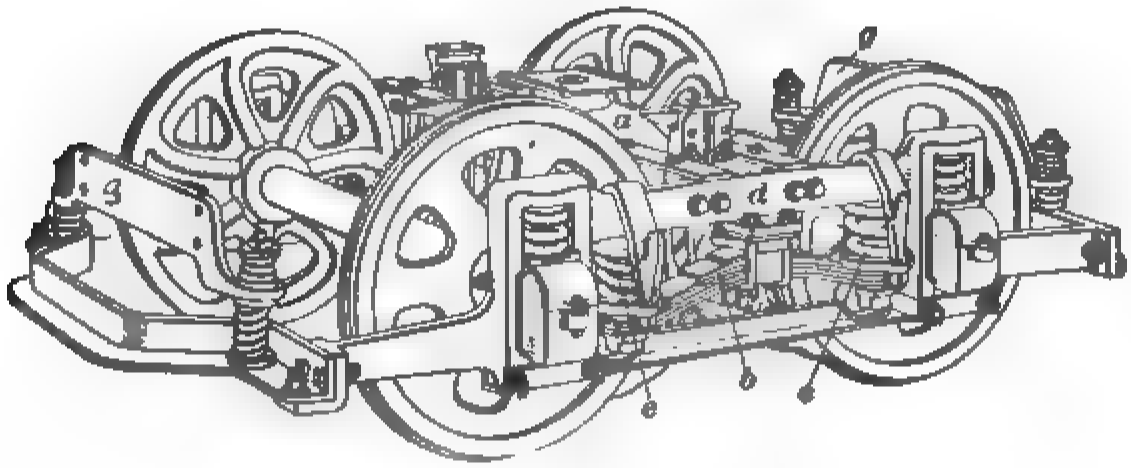


FIG. 15

the truck frame and car body. For short cars, springs placed close to the wheels would be sufficient, although such a construction would have little merit. The reason for providing a longer spring base is to prevent oscillation, which is unpleasant for the passengers and hard on the car body. The oscillation when excessive diminishes the traction on the rising end of the car and causes the wheels to slip. For these reasons, the spring base is extended by

adding extra springs at $S_1, S_1$. The axle bearings are outside the wheels, to give stability to the car body, the journal-boxes $J$ being free to move vertically through a short distance controlled by a heavy coil spring.

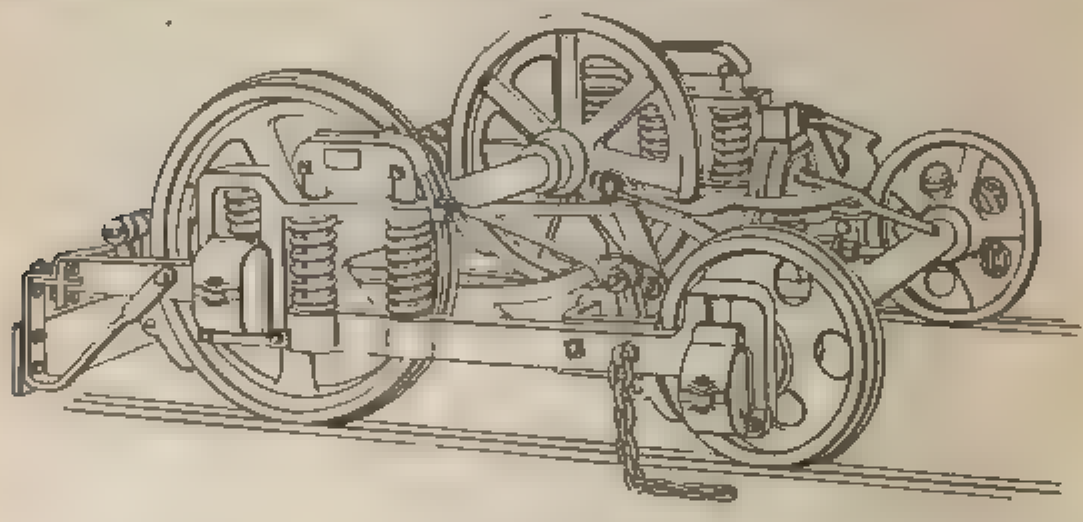


FIG. 16

Fig. 17 shows a larger view of the bearings used on a single-truck car; $a$ is the journal and $b$ the bearing brass, which is on the upper half only, because the thrust is all in one direction. This brass presses against the box casting $c$,

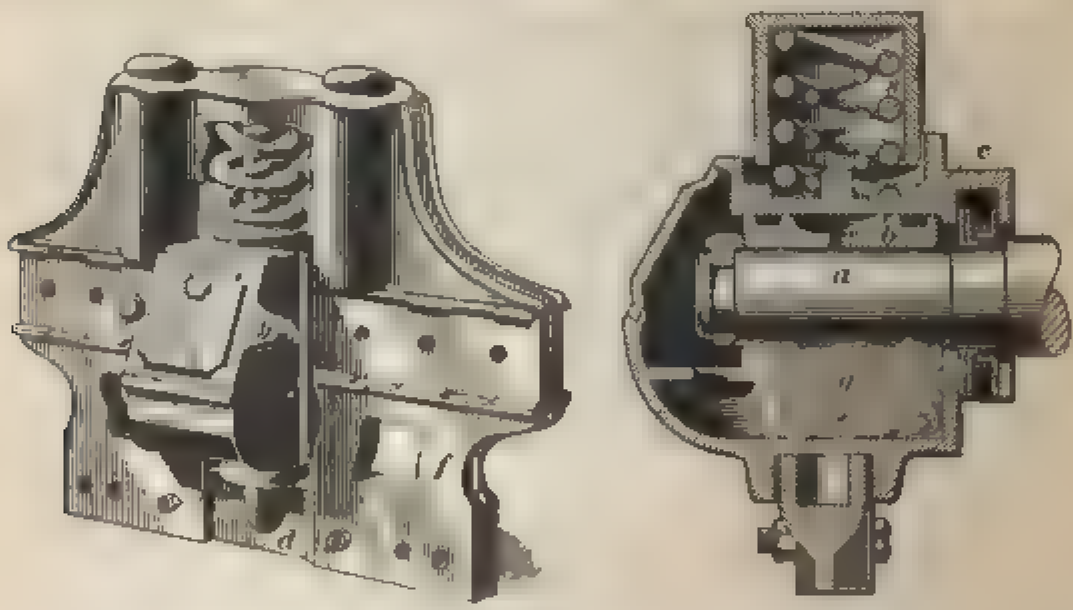


FIG 17

which in turn bears up against the spiral springs $s$, that are held in a socket in the frame $f$. By removing the piece $d$, the frame can be lifted clear of the axles. The journal is lubricated by means of waste $g$ in the lower part of the casing.

This waste is kept soaked with oil and effects the lubrication in the same manner as on ordinary railway cars. To guard the wheels against obstructions, the **pilots** *M*, *M*, Fig. 14, are bolted securely to the frame at a sufficient height from the track to avoid touching the rails.

In Fig. 15, the car body rests on the bolster *a*, carried by elliptical springs *b*. The weight resting on springs *b* is transmitted to the side frame *d* through equalizing coil springs *e* and links *f*. Fig. 18 shows, in detail, the relative arrangement of elliptical spring, equalizing bolt, equalizing spring, equalizing-spring link, and side frame.

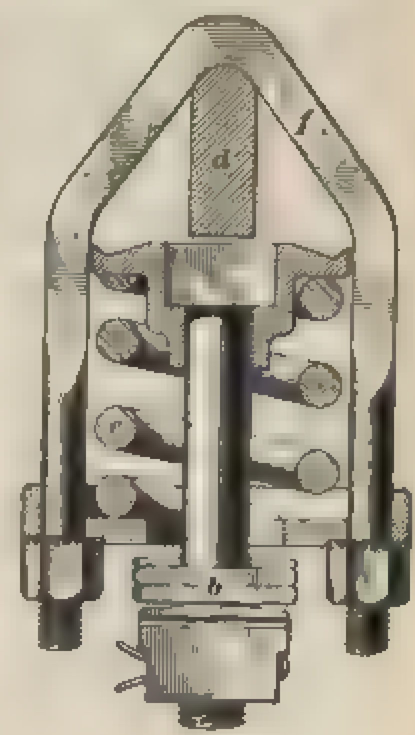


Fig. 18

**44.** The **wheel base**, that is, the distance between centers of axles on a truck, should be long enough to support the car body without excessive oscillation, but not so long as to make the wheels bind on curves. Any car body that calls for a wheel base of over 8 feet should be provided with double trucks; 7 feet is often given as the limiting wheel base for single-truck cars, but it is practicable to use an 8-foot base unless the curves are of unusually short radius. An 8-foot wheel base will require a much larger power expenditure on curves, but a car is rounding curves only a small part of the time it is in operation, and the increased power consumption is more than made up for by the increase in the size of the car that the longer wheel base makes possible. Excessive length of wheel base not only wears out the rails and wheels, but increases the power required to pull the car around a curve. If it takes a pulling force of 500 pounds to pull an 8-ton car with a 7-foot wheel base around a curve having a radius of 50 feet, it will take a pulling force of only 350 pounds to pull the same car around the same curve on a 4-foot base. To pull the car around a curve of 100 feet radius on a 7-foot

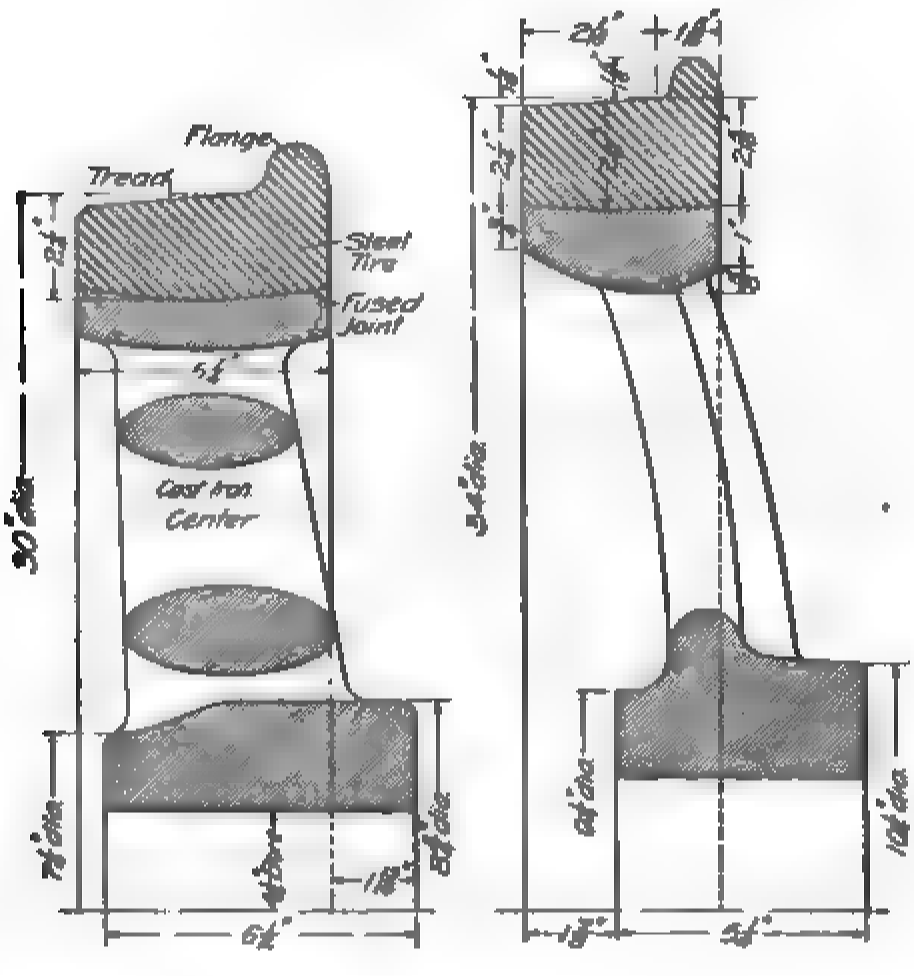
wheel base would require a pull of 255 pounds, and on a 4-foot base, 185 pounds. The difference in the pull required on the two bases on the 100-foot curve is much less than on the 50-foot curve, which goes to show that the greater the radius of the curve, the less difference does it make what the wheel base is. It is evident, then, that in laying out a road, all the curves should be made of as great a radius as possible; and in buying trucks for a road already installed, the radii of existing curves should be considered. With double-truck cars the wheel base may be anywhere from 4 to 7 feet. The 4-foot base would only be used where the curves are very short, the ordinary base for such trucks being 6 feet. For very heavy interurban traffic, a 6½-foot or 7-foot wheel base is frequently necessary to allow room enough for the motors when hung between the axles.

To enable cars to round curves with the least effort and to save the rails and flanges, guard-rail flanges at curves should be kept clean and well greased. Other points to be considered are in regard to the treads and flanges of the wheels; on them depends very much the ease with which a car will take a curve. The treads should not be so wide that they run on the paving outside of the track, and the shape, depth, and width of the wheel flange should be governed by the shape, depth, and width of the rail groove.

**45. Wheels** used on electric cars vary from 30 inches to 36 inches in diameter; on ordinary street cars, the diameters are usually from 30 to 33 inches. For heavy work it is necessary to use wheels somewhat larger so as to give more clearance for the motors; therefore, diameters of 33 to 36 inches are quite common.

For light cars operating at low speed, cast-iron wheels with chilled treads are used. However, the ordinary chilled wheel is not strong enough for high-speed interurban work, and even for heavy city traffic at low speed it is giving place to the steel-tired wheel, which is provided with a tire made of rolled open-hearth steel. This type of wheel has long been used on steam roads for locomotives and passenger

coaches, but until the advent of heavy electric traction its use on electric roads was limited, owing chiefly to the high cost. The tire can be fastened to the cast-iron center by bolts, or retaining rings, but the usual method in wheels for electric cars is to fuse or cast-weld the tire to the center. The tire is heated, placed in the mold, and the iron center poured; the melted iron fuses the tire and a perfect joint




(a) (b)

FIG. 19

between the two results. The main advantages of steel-tired wheels that compensate for their high cost as compared with chilled cast-iron wheels are: (*a*) Greater strength and security; these wheels are not likely to fly to pieces no matter how high the speed may be or how severe the strains due to rough track or very cold weather. (*b*) They are not nearly so liable to develop flat spots. (*c*) They are not so liable to slip, since the wrought steel tire has, with the steel rail, a much higher coefficient of friction than a chilled

cast-iron wheel; this reduces slippage and trouble due to flat spots; the action of the brakes is also much more effective. (*d*) They avoid trouble due to chipped or broken flanges. (*e*) The rim can be made thick, so that the wheel will wear a long time before becoming useless; with chilled wheels, the depth of chilled iron is limited.

Fig. 19 shows sections of two fused steel-tired wheels; (*a*) is a 30-inch wheel used on trail cars for an elevated road; (*b*) is a 34-inch wheel for an interurban road. The weight of (*a*) is 650 pounds, and of (*b*) 688 pounds.

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### METHOD OF SUSPENDING MOTORS ON TRUCK

**46.** In practically all cases, the motors on an electric car drive the axles through single reduction spur gearing, a pinion on the armature shaft meshing with a gear fastened to the axle. Direct-connected motors, i. e., motors having the armature mounted on the axle, have been tried, but have

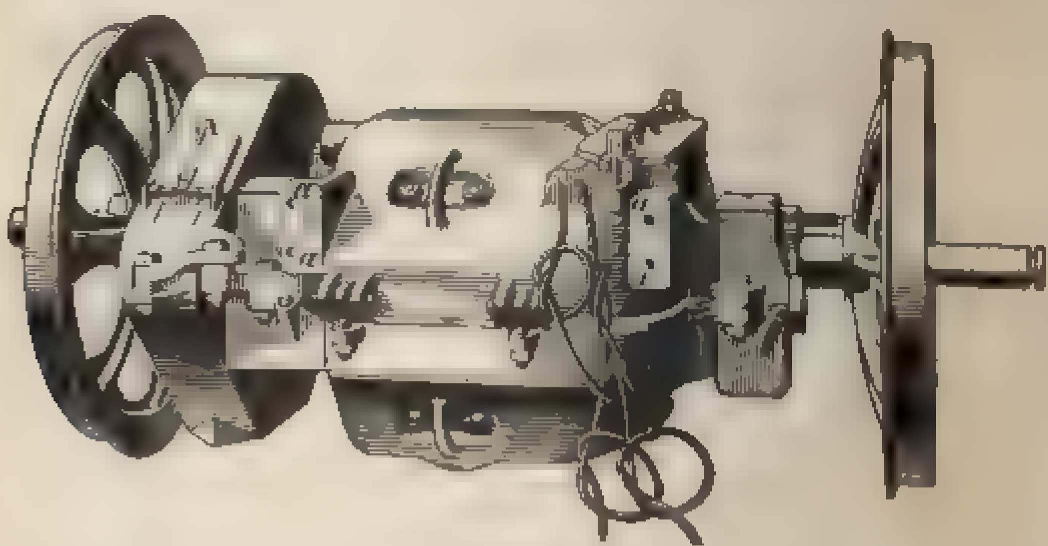

FIG. 20

never proved a success except in some special types of electric locomotive where the motors are of such large size that they can be designed to operate satisfactorily at the low speed necessitated by direct connection.

**47.** Figs. 20 and 21 show the ordinary *nose suspension*, which is by far the most common method of suspending railway motors. Fig. 20 shows a G. E. (General Electric) 52

motor mounted on the wheels; the axle passes through the axle bearings at the rear of the motor and the front is supported by a suspension bar bolted to the motor at *a a*, *a a* and resting on springs carried by the side frames of the truck. In Fig. 21, the axle *a* passes through the axle bearings *b*, *b* and the motor is prevented from shifting along the

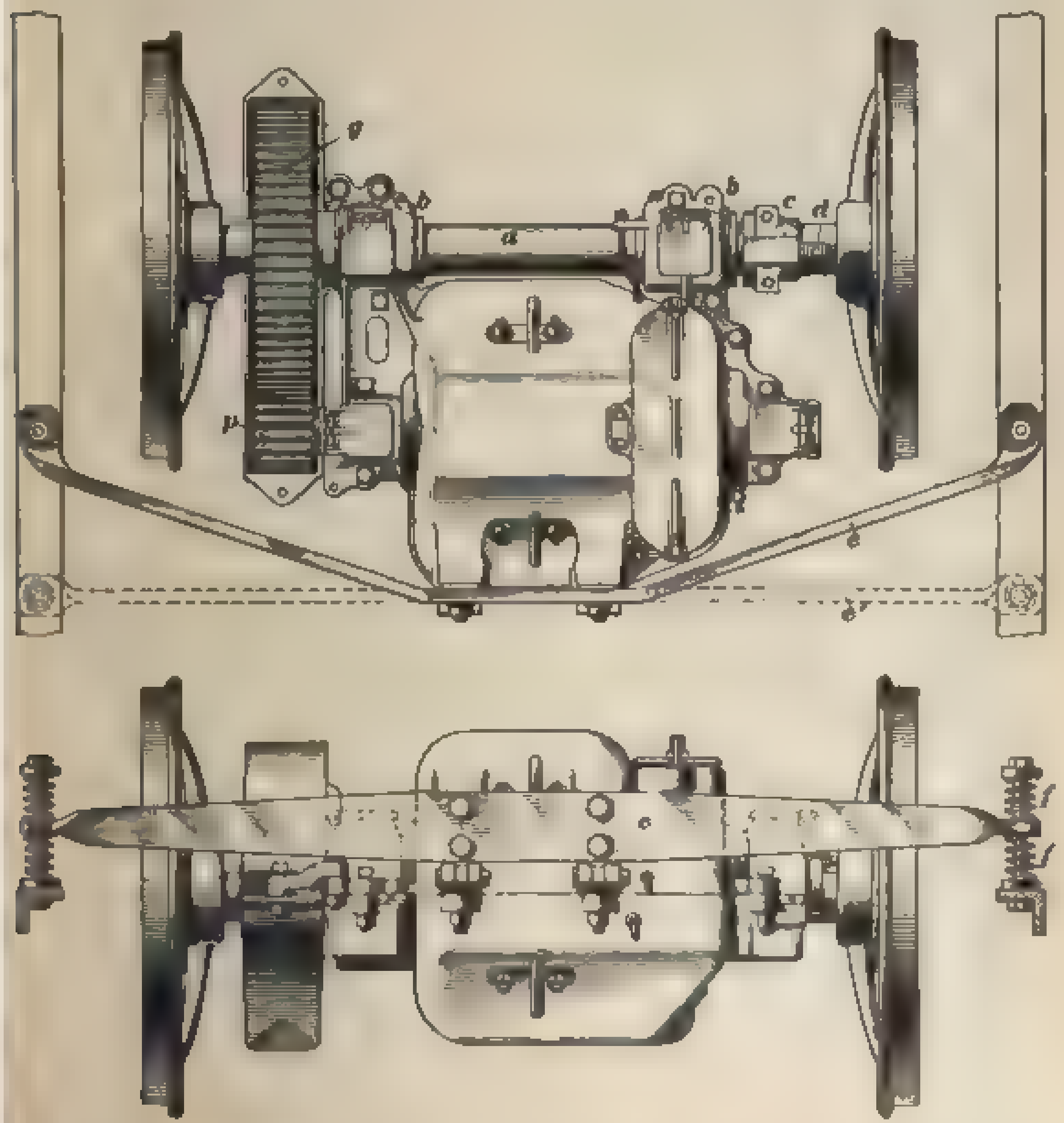

FIG. 21

axle on the one hand by gear *g* and on the other by collar *c*, the location of which can be adjusted by screw *d*. This is a comparatively small motor, and it does not take up all the space between the wheel hubs; with large motors, the space between hubs is often completely filled and no collar is

necessary. Instead of a split collar *c* with a screw adjustment, it is now common practice to use a plain solid collar pressed on to the shaft in the same way as the wheels; it is cheaper than the collar shown in Fig. 21 and there is no possibility of its working loose. The suspension bar may be straight, as shown at *e'*, or bent, as at *e*, but in either case it is supported by springs *f*, *f* carried on the side frames of the truck. In Fig. 15, *g*, *g* show the arrangement of suspension bars for a double truck where the motors are hung outside the axles. For double-truck cars used in city service, the wheel base is frequently not large enough to allow hanging the motors inside the axles, but for large interurban cars where the wheel base is from 6 to 7 feet there is enough room between the axles and bolster to take the motors and they are therefore placed inside the axles, thus making a much more compact arrangement.

No matter what kind of suspension is used, the object is to provide a flexible support for the motor so as to cushion the pounding effect and allow a certain freedom for up and down movement as the car passes over irregularities in the track.

**48.** Fig. 22 shows a G. E. 74 motor, with nose suspension, mounted on 33-inch wheels. This is a rather large motor (65 horsepower) and takes up all the space between wheel hubs; an axle collar is therefore unnecessary. This motor is designed to be worked on from above rather than from a pit and the upper half of the field frame can be removed and the armature taken out from above without disturbing the lower half of the motor. The suspension bar is therefore bolted to the lower half of the motor instead of the upper half, as shown in Fig. 21, which represents the older arrangement.

**49. Westinghouse Cradle Suspension.**—Fig. 23 shows a method of suspension used considerably with Westinghouse motors in which the motor is supported by a cradle or frame *A A*. The front of the cradle is supported by a cross-bar that rests on the truck side frames, and the back

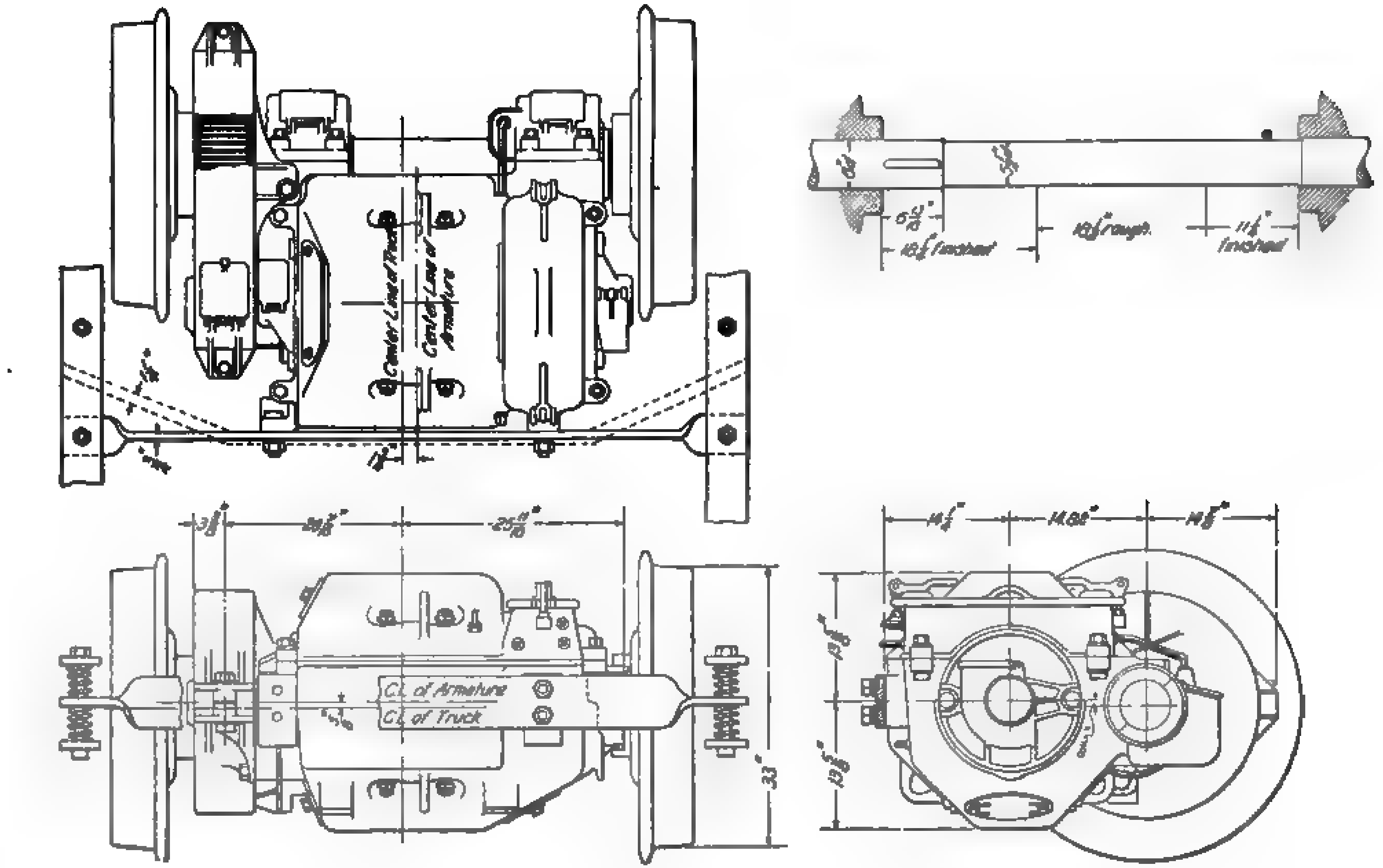
Center Line of Truck
Center Line of Armature
C.L. of Armature
C.L. of Truck
33"
14.88"
rough
finished

Fig. 22

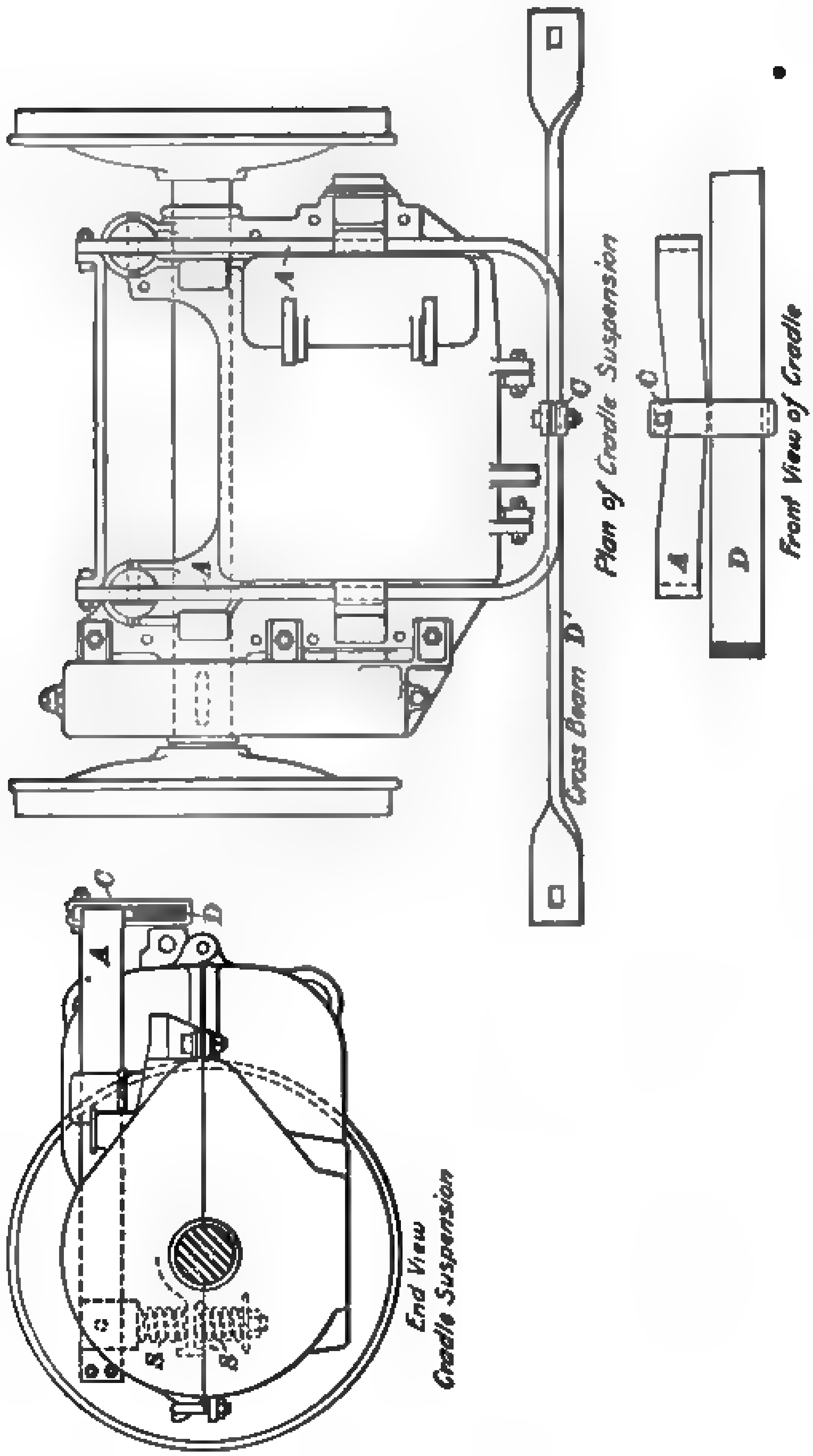
A
A
C
D'
Cross Beam
Plan of Cradle Suspension
C
A
D
Front View of Cradle
C
D
A
S
S
End View
Cradle Suspension

FIG. 28

by means of springs *S*, *S'* that bear against lugs cast on the same arm that carries the axle bearings. The sides of the cradle pass through lugs on the ends of the motor and the whole motor is free to move up and down through a limited range, the movements being cushioned by springs *S*, *S'* and those placed between the ends of the cross-beam and the truck side frame.

# MOTORS AND CONTROLLERS

## STREET-RAILWAY MOTORS

### INTRODUCTION

**1. Street-railway motors** have to meet several conditions not imposed on motors used for stationary work. Their design is limited to a large extent by the fact that they must be placed wholly beneath the car. They must be dust-proof and waterproof, because they may have to run through all kinds of dirt and water, and must be arranged so that they can be readily suspended from the car axle. Railway motors must be substantial in every particular, because they are called on to stand harder usage than almost any other kind of electrical machinery.

Practically all railway motors, whether for direct or alternating current, are of the series-wound type. For this service, a motor must be able to give a strong starting effort and an increasing torque with decreasing speed. Shunt-wound motors run at a nearly constant speed regardless of load, and a car equipped with them would ascend grades at about the same speed that it would run on the level; whereas, a series-wound motor, when the load is increased, will decrease its speed automatically. Variable speed is essential for railway operation and the shunt-wound motor is a constant-speed machine; hence, it has never been used, to any extent, for this class of work. Another great advantage of the series motor is that it can be made to exert a very strong starting effort. All current that flows through the armature also flows through the field, and a very strong field is thus obtained at starting. With a shunt motor, the current in the

field is fixed by the resistance of the winding and the line E. M. F.; consequently, the field cannot be strengthened when an especially strong torque is desired. Another incidental advantage of the series motor is that the field coils consist of a few turns of coarse wire and are much more substantial and cheaper to wind than fine-wire shunt coils.

**2. Speed Reduction.**—It has not been found practicable or economical to drive ordinary electric cars by means of motors having their armatures mounted directly on the axles, though such motors may be used to advantage in special cases when they are of large size, as, for example, on heavy, high-speed, electric locomotives. For ordinary work, motors are always geared to the axle; a pinion on the armature shaft engages with a gear keyed to the axle, both gears being covered by a gear-case that contains a quantity of heavy oil. The reduction in speed depends on the relative number of teeth in the two gears; the smaller the pinion, as compared with the gear, the greater will be the reduction.

The **gear-ratio** of an equipment will here be understood as the ratio of the number of teeth in the gear to the number in the pinion; this is the more usual way of expressing it, though it is sometimes given as the ratio of the number of teeth in pinion to the number in gear. The pinion has, in nearly every case, a number of teeth considerably smaller than that in the gear, so that there is little cause for confusion no matter which way the ratio is stated. If, then, a motor has 14 teeth in the pinion and 68 in the gear, the gear-ratio is $\frac{68}{14} = 4.86$ and the motor armature runs 4.86 times as fast as the axle. Table I gives the speed of car axles, in revolutions per minute, for different car speeds and diameters of wheels. By multiplying the revolutions given in the table by the gear-ratio in any given case, the speed of the motor armature is obtained.

EXAMPLE.—A car is mounted on 33-inch wheels and runs at a speed of 20 miles per hour; how many revolutions per minute do the motor armatures make if there are 65 teeth in the axle gear and 15 in the pinion?

SOLUTION.—The speed of the car axle, Table I, for 33-in. wheels and a speed of 20 mi. per hr., is 203.7 rev. per min. The gear has 65 teeth and the pinion 15, hence the gear-ratio is $\frac{65}{15} = 4.33$. The speed of the armature is, therefore, $203.7 \times 4.33 = 882$ rev. per min., approximately. Ans.

TABLE I

REVOLUTIONS OF CAR AXLE CORRESPONDING TO VARIOUS CAR SPEEDS

| Speed of Car Miles per Hour | Speed of Car Feet per Minute | Speed of Car Axles (Revolutions per Minute) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 30-Inch Wheels | 31-Inch Wheels | 32-Inch Wheels | 33-Inch Wheels | 34-Inch Wheels | 35-Inch Wheels | 36-Inch Wheels |
| 6 | 528 | 67.2 | 65.0 | 63.0 | 61.1 | 59.3 | 57.6 | 56.1 |
| 8 | 704 | 89.6 | 86.7 | 84.0 | 81.5 | 79.1 | 76.8 | 74.7 |
| 10 | 880 | 112.0 | 108.4 | 105.0 | 101.8 | 98.9 | 96.1 | 93.4 |
| 12 | 1,056 | 134.4 | 130.0 | 126.0 | 122.2 | 118.6 | 115.2 | 112.1 |
| 14 | 1,232 | 156.9 | 151.7 | 147.0 | 142.6 | 138.4 | 134.5 | 130.7 |
| 16 | 1,408 | 179.2 | 173.4 | 168.0 | 163.0 | 158.2 | 153.6 | 149.4 |
| 18 | 1,584 | 201.7 | 195.1 | 189.0 | 183.4 | 178.0 | 172.9 | 168.1 |
| 20 | 1,760 | 224.0 | 216.8 | 210.0 | 203.7 | 197.8 | 192.1 | 186.8 |
| 22 | 1,936 | 246.5 | 238.4 | 231.0 | 224.1 | 217.5 | 211.3 | 205.5 |
| 24 | 2,112 | 268.8 | 260.0 | 252.0 | 244.4 | 237.3 | 230.4 | 224.2 |
| 26 | 2,288 | 291.3 | 281.8 | 273.0 | 264.8 | 257.1 | 249.7 | 242.9 |
| 28 | 2,464 | 313.8 | 303.4 | 294.0 | 285.2 | 276.8 | 268.9 | 261.4 |
| 30 | 2,640 | 336.1 | 325.1 | 315.0 | 305.6 | 296.6 | 288.2 | 280.2 |
| 32 | 2,816 | 358.4 | 346.8 | 336.0 | 326.0 | 316.4 | 307.4 | 298.8 |
| 34 | 2,992 | 380.9 | 368.4 | 357.0 | 346.3 | 336.2 | 326.6 | 317.6 |
| 36 | 3,168 | 403.4 | 390.2 | 378.0 | 366.7 | 356.0 | 345.8 | 336.2 |
| 38 | 3,344 | 425.8 | 411.8 | 399.0 | 387.1 | 375.7 | 365.0 | 354.9 |
| 40 | 3,520 | 448.0 | 433.6 | 420.0 | 407.4 | 395.6 | 384.2 | 373.6 |
| 42 | 3,696 | 470.6 | 455.2 | 441.0 | 427.8 | 415.3 | 403.5 | 392.3 |
| 44 | 3,872 | 493.0 | 476.8 | 462.0 | 448.1 | 435.1 | 422.6 | 411.0 |
| 46 | 4,048 | 515.4 | 498.5 | 483.0 | 468.5 | 454.8 | 441.9 | 429.7 |
| 48 | 4,224 | 537.6 | 520.0 | 504.0 | 488.8 | 474.6 | 461.1 | 448.4 |
| 50 | 4,400 | 560.2 | 541.8 | 525.0 | 509.2 | 494.4 | 480.3 | 467.0 |

**3.** Various gear-ratios are used in practice, depending on the size of the motor and the speed at which the cars must run. Usually, the axle gear has from two to five times as many teeth as the pinion, the first value being found only on heavy high-speed cars. For ordinary city street cars, the

gear will usually have from four to five times as many teeth as the pinion. Involute teeth are used and the diametral pitch for ordinary street-car gears is three; i. e., there are three teeth for each inch diameter of the pitch circle. For heavy traction work, gears having a diametral pitch of two and one-half are employed in many cases. The distance between gear-centers for a given motor is fixed, hence the sum of the circumferences of the two pitch circles is fixed and any increase in the number of teeth in one gear must be accompanied by a corresponding decrease in the other; the sum of the number of teeth in the two gears must be constant. For example, suppose that a motor has a 15-tooth pinion meshing with a 65-tooth gear; if the speed of the car is to be reduced by using a 14-tooth pinion, a 66-tooth gear must be used. No matter what combination of gear and pinion is used, the total number of teeth must be 80, otherwise with the given distance between centers, the gears will not mesh properly.

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### SELECTION OF MOTORS

**4.** The selection of the type of motor for a given service is a subject that cannot be given too careful consideration. If the motors are not powerful enough, the cars will not be able to maintain the required schedule; or if forced to do so, there will be a large number of breakdowns and the bill for repairs will be heavy to say nothing of the loss due to interference with the traffic. On the other hand, if motors much larger than required are installed, an unnecessary outlay of capital is entailed and the road is burdened with an expense that might have been avoided. Again, unnecessarily large and heavy motors involve a waste of power, because of the extra weight that must be propelled and also, to some extent, because of the greater iron losses in the larger motor. Finally, excess of weight means unnecessary pounding of joints and deterioration of track.

In order to secure the best results, the selection can be made only after a careful consideration of all local conditions

affecting the power necessary to propel the cars. It is better to have the motors a little too large than too small, but at the same time it is not economical, from either the standpoint of investment or power consumption, to install motors much larger than are necessary.

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### RATING OF MOTORS

**5.** There has been much discussion as to the manner in which the output of street-railway motors should be expressed. The load that a motor can carry is limited by the heating effect, and it has become customary to rate motors according to the output, or brake horsepower, that they will deliver continuously for a period of 1 hour with a limiting rise in temperature of 75° C. above surrounding air at 25° C. For example, according to this rating, a 150-horsepower railway motor is one that will deliver 150 horsepower for 1 hour with a rise in temperature not exceeding 75° C. above the temperature of surrounding air at 25° C. This method of rating is not wholly satisfactory, but it is useful in giving a comparative idea as to the capacities of motors and it is also of value in that it shows the performance of the motor as regards sparking and general behavior of the commutator and brushes. Moreover, it is a difficult matter to give a motor a shop test that exactly duplicates its service conditions; whereas, the 1-hour test at full load is easily applied.

**6. Service Capacity.**—In order to express more closely the output of which motors are capable in regular service, they are now very generally rated by the current that they can carry continuously, without overheating, under conditions that duplicate, as far as possible, those met with in regular service.

The heating of a motor is due to the $I^2R$ loss in the windings and the core loss in the armature. The copper losses depend on the current, which, on a car in regular operation, is continually changing in amount. The current is large at starting, but rapidly falls off as speed is attained; while at times the car may coast along without any current. The

heating effect of the current is proportional to the square of the current at any given instant and the heating effect of the variable current will be the same as a steady current equal in amount to the square root of the mean square of the various values of the variable current. If then a motor is to operate without overheating, this square-root-of-mean-square, or effective, value must not exceed that which the motor could carry continuously and not for 1 hour only. It should be noted that the effective current is not the same as the average current taken by the car. If a test be made on a car during an extended run, the current can be recorded by means of a recording ampere meter or the total quantity of electricity applied can be measured by means of an ampere-hour meter. The number of ampere-hours divided by the number of hours during the test run gives the average value of the current. The heating effect is, however, proportional to the effective value and not to the average value, and the effective value can be found by taking the square of the current at sufficiently close intervals, finding the average value of these squares and extracting the square root of the average so found. In fact, the terms average and effective have here the same meanings that were explained in connection with alternating currents. The effective value of the current must be obtained from the current curve, because this curve is very irregular and does not follow any fixed law. There is no fixed relation between the effective value and the average value, though for a given class of service the relation can be determined approximately. The effective value may be anywhere from 25 to 100 per cent. greater than the average value, depending on the kind of service; for ordinary street-car service it will be about 35 per cent. greater. If, therefore, a number of trial runs showed that each motor of a car had to carry an average current of 30 amperes, the effective current would be approximately $30 + .35 \times 30 = 40.5$ amperes and the motors selected for the work should be able to carry continuously a steady current of this amount. On the other hand, a motor rated as being able to carry a steady current of, say, 30 amperes, should

not be made to carry an average current of more than $\frac{30}{1.35} = 22.2$ amperes in regular service. These values are, of course, only approximate, because the variable character of the service, number of stops, grades, curves, etc., make it practically impossible to give any relation between average and effective current that will be applicable to all classes of service.

**7.** In testing a motor to determine its service capacity, the voltage applied should be the average voltage on which the motor operates when used on a car. The core loss increases with the voltage, because the higher the voltage the higher is the speed of the armature and the more rapid are the reversals of the magnetism in the core. When a motor is in operation on a 500-volt circuit, the average voltage applied is not 500 volts but is usually considerably less. When the car is at a standstill, no pressure is applied; and when being started a part of the applied pressure is taken up in the starting resistance. Again, as explained under the heading Speed Control, there are times when two motors are connected in series across the line, under which condition the pressure applied to each motor is only one-half the line voltage, or about 250 volts. For these reasons, the average pressure applied to the motors in ordinary city traffic will seldom exceed 300 volts, and even in suburban traffic, where there are fewer stops, it will not often exceed 400 volts. In giving the rating of a motor in terms of the current that it can carry continuously, it is necessary, therefore, to state also the average voltage at which the current is supplied; in many cases, two current ratings are given, one at an average pressure of 300 volts and the other at 400 volts.

## MOTOR CHARACTERISTICS

**8.** In determining the suitability of a motor for a given class of service, it is necessary to have information showing the performance of the motor. This is obtained from tests

made by the manufacturers, and is usually given in the form of curves, known as **motor characteristics**, that show the relation between the current, speed, tractive effort, brake horsepower, and heating effect. Fig. 1 is a set of these curves for a No. 68 Westinghouse motor.

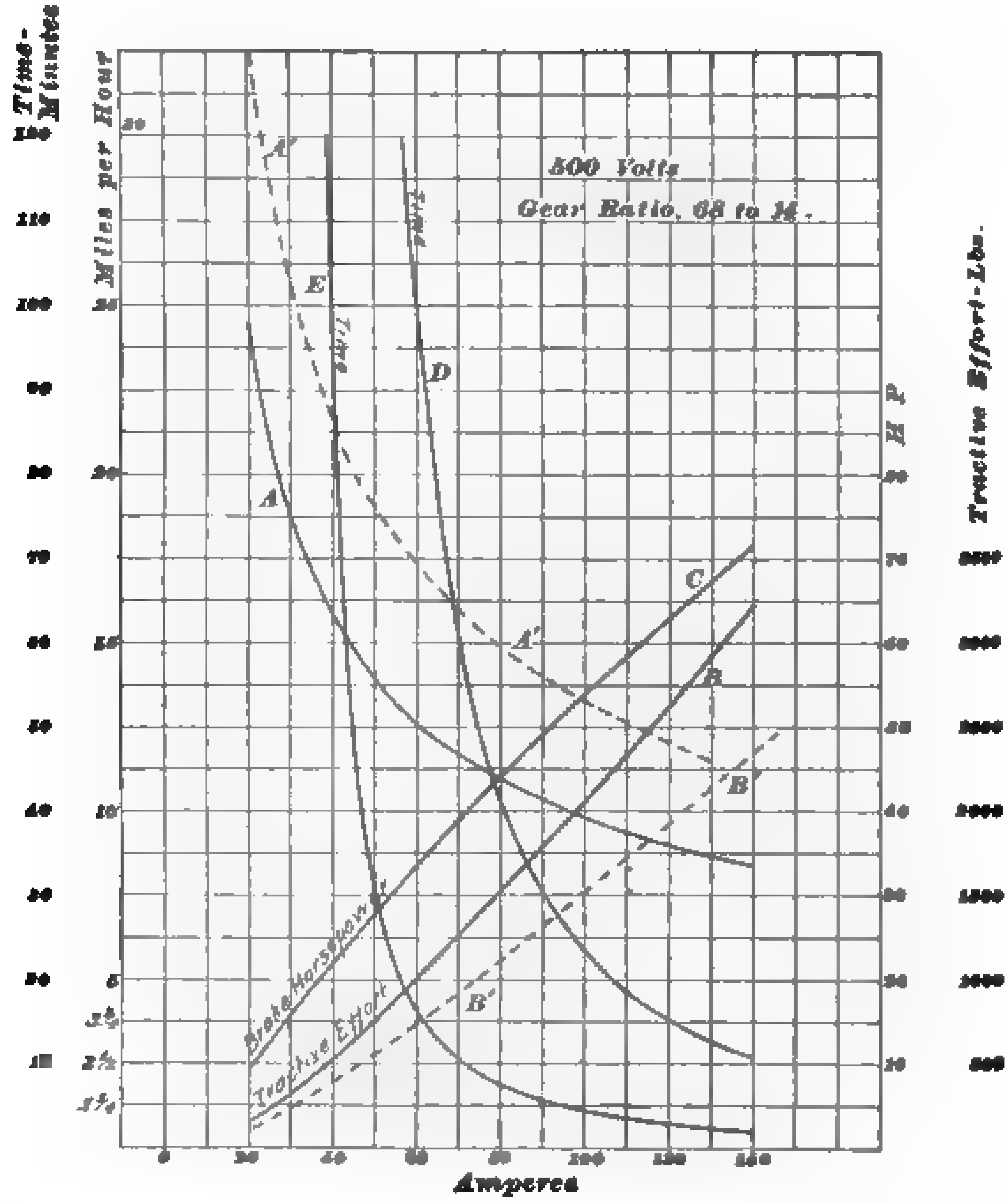


FIG. 1

**9. Speed Characteristic.**—The curves, Fig. 1, are drawn for a constant applied E. M. F. of 500 volts, which is the normal voltage at which the motor is intended to operate. As the current increases the speed decreases,

because of the increase in field strength, and the speed of the car, therefore, decreases as shown by the speed curve $A$. The speed of the car corresponding to any given current depends on the gear-ratio and the diameter of the wheels, hence both of these must be stated in connection with the curves. In this case, there are 14 teeth in the motor pinion and 68 in the axle gear, and the wheels are 33 inches in diameter. A curve showing the relation between armature speed and current would have the same general shape as $A$.

**10. Effect of Increase in Voltage.**—An increase in voltage increases the speed in almost direct proportion. For example, in Fig. 1, the speed corresponding to 60 amperes is 12.5 miles per hour; if the pressure were increased from 500 volts to 600 volts, the speed corresponding to the same current would be approximately $12.5 \times \frac{600}{500} = 15$ miles per hour.

**11. Tractive Effort Characteristic.**—Curve $B$ shows the relation between current and tractive effort. This, of course, refers to the effort exerted by a single motor and gives the total force at the two wheels on which the motor is mounted; thus, for a current of 50 amperes, the total tractive effort at the rail head is 750 pounds, or 375 pounds at each driving wheel. The torque of a series motor increases rapidly with the current; hence, the tractive effort also increases, curve $B$ having the same general shape as one showing the relation between motor torque and current.

**12. Relation Between Motor Torque, Gear-Ratio, Speed, and Tractive Effort.**—Fig. 2 shows the forces acting on a car wheel, gear, and pinion; $r$ is the radius of the pitch circle of the pinion, $r'$ that of the gear, and $r''$ that of the car wheel. When current flows through the motor, the torque or twisting action that is exerted on the armature and pinion depends on the value of the current and the electrical design of the motor. The motor torque will be $F' r$, when $F'$ is the force exerted at the pitch circle; torque is always expressed as force $\times$ radius and

must not be confused with the force $F'$. For a given torque, $F'$ will vary with the radius of the pinion, but the product $F'r$ will remain constant, because if $r$ is increased or decreased $F'$ will be decreased or increased by a corresponding amount. The torque exerted on the axle is $F'r'$ and is greater than $F'r$ because the radius, or lever arm $r'$, is greater than $r$. Since the number of teeth in a gear is proportional to its diameter or radius $\frac{r}{r'} = \frac{n}{n'}$, or $r' = r\frac{n'}{n}$, where $n$ is the number of teeth in the pinion and $n'$ the num-

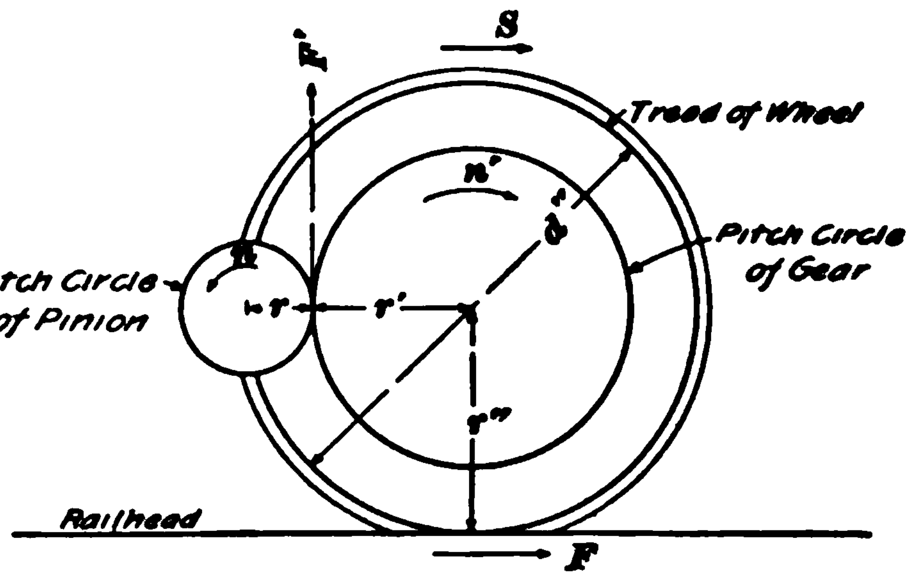


FIG. 2

ber of teeth in the gear. The torque exerted on the axle is $F'r'$, or $F' \times r\frac{n'}{n} = F'r \times \frac{n'}{n}$. But $F'r$ is the motor torque, hence the torque exerted on the axle is equal to the motor torque multiplied by the number of teeth in the gear and divided by the number of teeth in the pinion, or, in other words, the torque exerted on the drivers is equal to the motor torque multiplied by the gear-ratio.

The total tractive effort $F$, Fig. 2, exerted at the rail head by both wheels, is equal to the torque $F'r'$ divided by the wheel radius $r''$. Thus, $F = \frac{F'r'}{r''} = F'\frac{r\frac{n'}{n}}{r''} = \frac{F'r}{r''} \times \frac{n'}{n}$. If $F'r$ is expressed in pound-feet, and, if instead of $r''$, the wheel diameter $d''$ is used, the formula becomes

$$F = \frac{24\,F'r}{d''} \times \frac{n'}{n} \qquad (1)$$

where $F$ = total tractive force, in pounds per motor;
$F' r$ = motor torque, in pound-feet;
$d''$ = diameter of wheel, in inches;
$n'$ = number of teeth, in gear;
$n$ = number of teeth, in pinion.

**Example.**—A car is equipped with motors, having 15-tooth pinions and 65-tooth gears, mounted on 33-inch wheels. What will be the tractive effort per motor when the current is such as to give a motor torque of 300 pound-feet?

**Solution.**—In formula **1**, $F' r = 300$, $d'' = 33$, $n' = 65$, $n = 15$. Hence,

$$F = \frac{24 \times 300}{33} \times \frac{65}{15} = 945 \text{ lb., approximately. Ans.}$$

**13.** The number of feet traveled per minute by a car is $\frac{3.1416\, d'' s'}{12}$, where $d''$ is the wheel diameter, in inches, and $s'$ the axle speed, in revolutions per minute. Since 1 mile per hour is equivalent to 88 feet per minute, the speed, $S$, of the car, in miles per hour, is $S = \frac{3.1416\, d'' s'}{12 \times 88}$ or

$$S = \frac{d'' s'}{336.1} \qquad (2)$$

**14. Effect on Speed of Change in Gear-Ratio.**—In Fig. 1, the curves of tractive effort and speed are drawn for a gear-ratio of 68 to 14 and for 33-inch wheels. Assuming that the wheel diameter remains unchanged, let us see what change will be made by substituting gears having a ratio of 64 to 18. The ratio is thus decreased from $\frac{68}{14} = 4.86$ to $\frac{64}{18} = 3.56$. From formula **2**, the car speed is $S = \frac{d'' s'}{336.1}$. But $s'$, the speed of the axle, is equal to $\frac{s}{\frac{n'}{n}}$, where $s$ is the motor speed and $\frac{n'}{n}$ the gear-ratio; hence, $S = \frac{d'' s}{336.1 \frac{n'}{n}}$. For a given current, the speed $s$ of the motor has a certain fixed

value and if $\frac{n'}{n}$ is made smaller, i. e., if the number of teeth in the gear is decreased and the number in the pinion correspondingly increased, it follows that, for the given current, the speed $S$ of the car will be increased. The speed corresponding to the new gear-ratio will be equal to the speed at the original ratio multiplied by the original ratio and divided by the changed ratio. In this case, the original ratio is $\frac{68}{14} = 4.86$ and the changed ratio $\frac{64}{18} = 3.56$. Taking a current of, say, 50 amperes, the speed with the original ratio is, from curve $A$, about 13.8 miles per hour. With the changed ratio, the speed corresponding to the same current would be $\frac{13.8 \times 4.86}{3.56} = 18.8$ miles per hour. In order, however, to obtain the higher speed with the same current, the weight of car would have to be lessened. By calculating the speed corresponding to various currents, the dotted curve $A'A'$ can be drawn to represent the speed for all current values at the new gear-ratio $\frac{64}{18}$.

15. **Effect on Tractive Effort of Change in Gear-Ratio.**—A change in gear-ratio affects the tractive effort as well as the speed. For a given current, the power delivered by the motor remains the same, no matter what the speed or tractive effort may be. A decrease in the gear-ratio causes an increase in speed, as indicated by curve $A'A'$; and, as the power curve $C$ remains unaltered, the increased speed corresponding to a given current must be accompanied by a decreased tractive effort. This is also plain from formula **1**, in which any decrease in $\frac{n'}{n}$ makes $F$ smaller. The tractive effort with the changed ratio will therefore be equal to the tractive effort with the original ratio, multiplied by the changed ratio and divided by the original ratio. For example, in Fig. 1, the tractive effort for a current of 50 amperes is 750 pounds with the original ratio; with the

new ratio, the effort will be $\frac{750 \times 3.56}{4.86} = 549$ pounds. By calculating the tractive effort corresponding to a number of different current values, the dotted curve $B'B'$ can be drawn, and curves $A'A'$ and $B'B'$ taken together represent the changed performance due to the change in gear-ratio from $\frac{68}{14}$ to $\frac{64}{18}$.

**16. Effect of Change in Wheel Diameter.**—With a given gear-ratio and current, a reduction in the wheel diameter causes a corresponding reduction in the speed of the car and vice versa. A decrease in the wheel diameter has the same effect as an increase in the gear-ratio.

**17. Effect of Changing Gear-Ratio on a Given Equipment.**—It is sometimes important to know the probable change that will be made in the speed of a given car when the gear-ratio is changed, the weight of the car and all other parts of the equipment remaining the same. If the motor characteristics for the original gear-ratio are at hand, the new speed under the changed conditions can be determined approximately, as follows: Calculate two curves, as explained for $A'A'$ and $B'B'$, Fig. 1, to suit the new conditions. From the known weight of car, the tractive effort can be determined approximately, and the speed and current corresponding thereto can be read off from the curves drawn for the new gear-ratio. For example, suppose that curves $A$ and $B$ represent the performance with the original gear-ratio of $\frac{68}{14}$ and that the ratio is changed to $\frac{64}{18}$. Curves $A'A'$ and $B'B'$ then represent the performance under the changed conditions. With the original gearing, a test showed that the car ran at a speed of 13.8 miles per hour on the level and required a current of 50 amperes per motor; the corresponding tractive effort was therefore 750 pounds per motor. With a fixed weight of car the increase in speed does not cause much change in the tractive effort and for low speeds, such as are now under consideration, it may be taken as

750 pounds under the changed conditions. With the changed gear-ratio, a tractive effort of 750 pounds corresponds to a current of about 61 amperes, as shown by curve $B'B'$; and a speed of about 17.25 miles per hour as shown by $A'A'$. The change in gear-ratio has therefore caused an increase in speed, but the increase is not as great as the mere change in gearing would lead one to expect. If the change in gearing alone were considered, the speed would be $\frac{13.8 \times 4.86}{3.56} = 18.8$ miles per hour. However, in order to drive the car at the higher speed, more power must be supplied and the current must therefore increase, thus necessitating an actual decrease in the motor speed. Because of this change in motor speed, with change in current, the final speed of the car must be determined from the characteristic curves for tractive effort and speed, drawn so as to take into account the change in gearing. Since, with a fixed weight of car, an increase in gear-ratio is accompanied by an increase in current, a point is soon reached beyond which any further change in gearing will cause serious overheating of the motors.

**18.** High-geared motors take very large currents during the acceleration period unless the controllers are carefully handled, and as a general rule motors should not be geared any higher than is necessary to allow the cars to maintain their schedule with a fair margin; any higher gearing simply causes waste of current and throws an unnecessary load on the equipment. In case the weight of the car is not fixed, a motor can be geared for higher speed without increasing the current. For example, a pair of motors might be taken off a heavy car and placed on a lighter one that requires a smaller tractive effort. If the limiting current is to be the same in each case, the motor torque and the speed of the armature will remain unchanged. Hence, assuming that the wheel diameters are not changed, the smaller tractive force can be obtained by increasing the gear-ratio and, since the armature speed remains constant, there will be a corresponding increase in the car speed. The power supplied to the

motors remains the same as when they were on the heavier car, the tractive effort being smaller and the speed correspondingly higher.

Therefore, in making changes in the gearing, the weight of car must be kept in mind; if it is not changed in any way, the increased speed may be obtained at the expense of overloading the motors; but if the motors are placed on a lighter car, the increased speed may be secured without any increase in the current or even with smaller current if the second car is very much lighter than the first.

**19. Heating Characteristics.**—Curve *D*, Fig. 1, shows the time that it takes the temperature of the motor to rise from 25° C. to 75° C. when carrying various currents. Thus, a load of 70 amperes can be carried for 60 minutes if the motor is started at a temperature of 25°, so that on the 1-hour rating this motor will have a capacity of about 38 brake horsepower. However, under ordinary running conditions, the motor is much hotter than 25° C., and the time during which it can carry a given current without rising above 75° C. will be much less than is indicated by curve *D*; the length of time that the motor can carry a given current without overheating is shown approximately by curve *E*, which allows for a rise of 20° C. in the interior of the motor after the motor has attained a temperature of about 55° C. For example, if it is running at 55° C., it will carry a steady current of, say, 50 amperes, or a variable current of which the effective value is 50 amperes, for 30 minutes before reaching 75° C. If the average working temperature were less than 55° C., the currents could be applied for a proportionally longer period without causing a temperature exceeding 75° C.; the current referred to is the current per motor, not the current per car. In making current tests on a motor, the ammeter should be connected in series with the motor and not in series with the trolley. Most cars are equipped with at least two motors operated in series at low speeds, in which case the current in each is the same as the total current, but at high speeds the motors are in parallel

and the current in each is approximately half the total. The average current per motor is, therefore, more than half the total current. Curve $E$ is useful in fixing the maximum loads that the motor may take during rush hours or periods of unusually heavy load.

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### EXAMPLES FOR PRACTICE

1. If a car is mounted on 34-inch wheels and the motors have a gear-ratio of $\frac{68}{16}$, what will be the total tractive effort per motor, when the motor torque is 300 pound-feet? Ans. 900 lb.

2. If the gearing on a car is changed as shown in Fig. 1, and if the tractive effort per motor remains constant, at 1,000 pounds, what will be the change in car speed caused by the change in gearing?
Ans. From 12½ mi. per hr. to about 15.3 mi. per hr.

3. A car is mounted on 33-inch wheels and the motors have a gear-ratio of $\frac{65}{15}$; what will be the speed of the armature, in revolutions per minute, when the car is running 16 miles per hour?
Ans. 706 rev. per min.

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## TYPES OF MOTORS

**20. Direct-current motors,** series-wound for 500 to 650 volts, are used on nearly all electric railways. At first, two-pole motors were used but these soon gave place to the four-pole type. Fig. 3 shows some of the field constructions used for well-known motors. (*a*) is the old Thomson-Houston W. P. 50 (waterproof) motor; it has a two-pole field with a single magnetizing coil. (*b*) is the old Edison No. 14, which has a four-pole field with two field coils. (*c*) is the General Electric 800 (G. E. 800) motor field which is similar to the Edison No. 14, but is turned up the other way. (*d*) shows the four-pole magnet frame introduced about 1891 by the Westinghouse Company in their No. 3 motor; it has four poles set on the diagonal, each pole being provided with a field coil. (*e*) shows a field about as used on a modern motor. The frame is of cast steel in order to secure lightness and the pole pieces, instead of being cast with the frame, are built up of sheet-iron stampings bolted

to the frame. This laminated-pole construction reduces heating in the pole pieces and also tends to keep down sparking at the commutator. The constructions indicated in (*a*), (*b*), (*c*), and (*d*) are now obsolete, but many motors in which they are used are still in operation.

Railway-motor armatures are always of the slotted type, the coils being wound on forms and then placed in slots on the core. In the earlier slotted armatures, a large number of slots were used, generally from 87 to 105. This was necessary because, if the slots were made coarse, it was found that they caused the magnetism in the pole pieces to

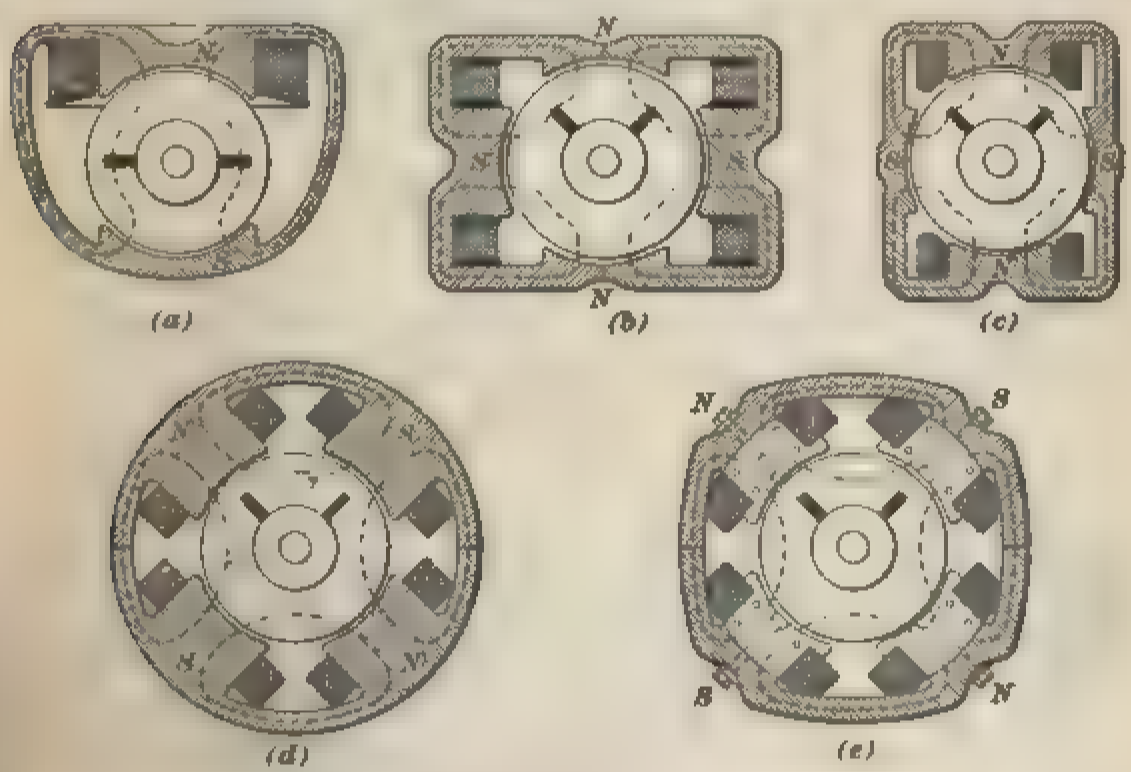

Fig. 3

vary to such an extent that the solid poles would heat considerably. By laminating the poles, it has been found possible to reduce the number of slots to about one-third the number formerly used, thus making them very much larger, cheapening the cost of production, and making the motor operate better generally.

A number of sizes and types of railway motors have been brought out from time to time by the leading manufacturing companies, in order to keep pace with improvements in design or to meet new traffic conditions. Some of the older

motors made by the General Electric Company were designated by the number of pounds tractive effort they could exert with full-load current when provided with standard gearing and mounted on 33-inch wheels. Thus, the G. E. (General Electric) 800 motor can exert a tractive effort of 800 pounds under these conditions; a G. E. 1,000 motor can exert 1,000 pounds; and so on. This method of rating has been abandoned and motors are now designated by arbitrary numbers, as, for example, G. E. 52, G. E. 54, etc. Westinghouse motors are also designated by numbers, as, for example, No. 3, No. 49, No. 56, etc. Table II gives the horsepower

TABLE II

OUTPUT OF RAILWAY MOTORS

| Type of Motor | Output in Horsepower (Railway Rating) | Type of Motor | Output in Horsepower (Railway Rating) |
|---|---|---|---|
| G. E. 800 . . . . | 27 | G. E. 73 . . . . . | 75 |
| G. E. 1,000 . . . | 35 | G. E. 74 . . . . . | 65 |
| G. E. 51B . . . | 80 | Westinghouse 12A | 30 |
| G. E. 52 . . . . | 27 | Westinghouse 38B | 50 |
| G. E. 54 . . . . | 25 | Westinghouse 49 . | 35 |
| G. E. 55 . . . . | 160 | Westinghouse 50L | 150 |
| G. E. 57 . . . . | 50 | Westinghouse 56 . | 60 |
| G. E. 66 . . . . | 125 | Westinghouse 69 . | 30 |
| G. E. 67 . . . . | 38 | Lorain No. 34 . . | 50 |
| G. E. 70 . . . . | 40 | | |

output, based on a run of 1 hour, with a rise in temperature of 75° C. above surrounding air at 25° C., for a number of the motors in most general use. Since all modern railway motors are very similar in their general construction, it will be sufficient to describe here a few typical examples.

G. E. 52 MOTOR

**21. Field-Frame Construction.**—As an example of a small motor intended for ordinary city traffic where light cars are operated, the **G. E. 52 motor** may be taken. Fig. 4 is a rear view showing the general shape of the field frame,

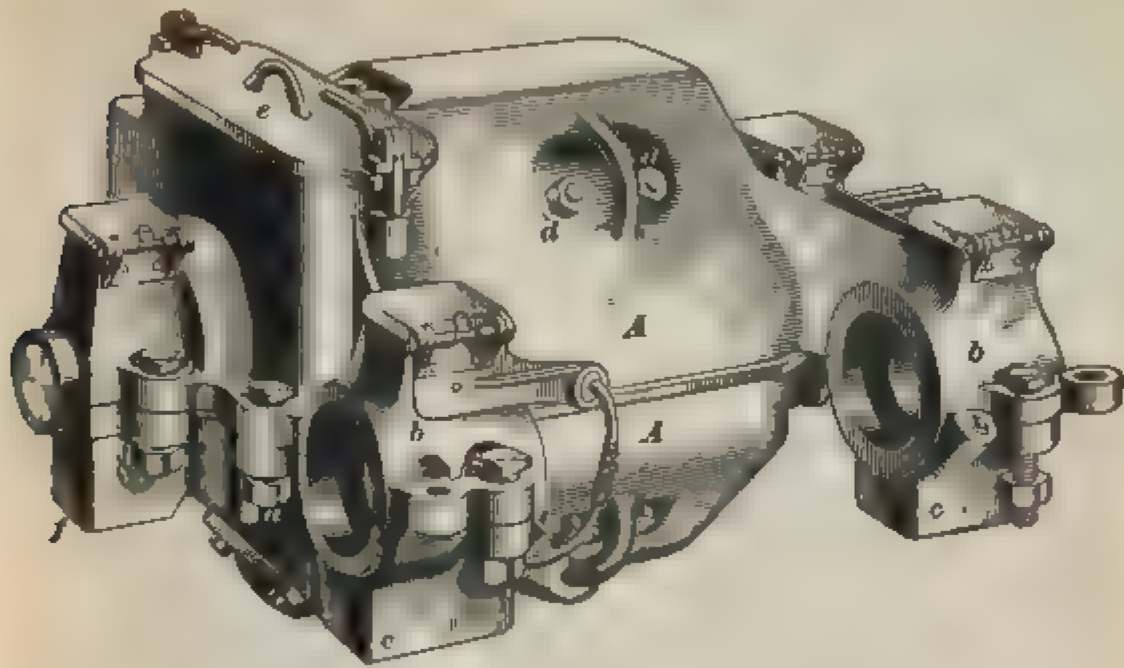


FIG. 4

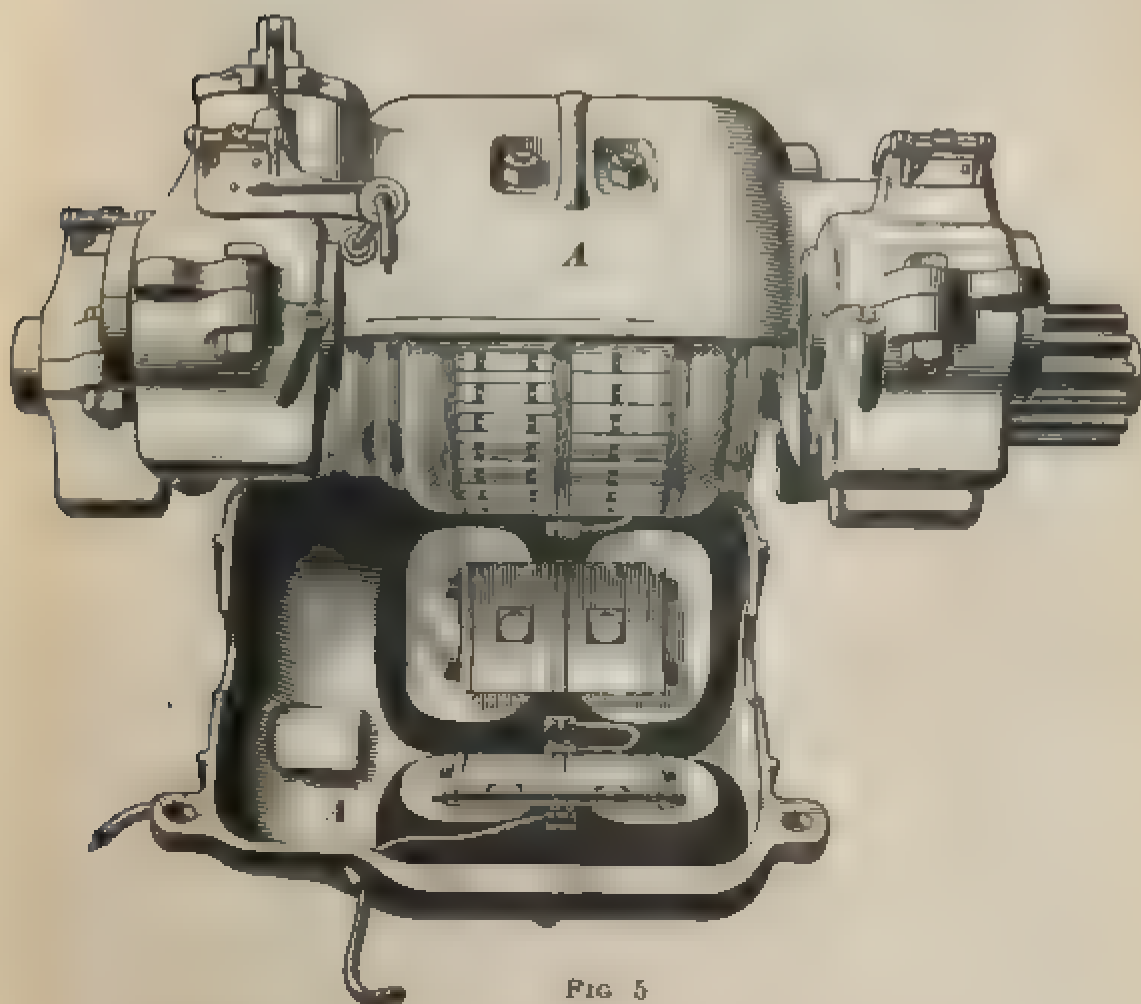


FIG 5

which, as in all modern motors, is shaped so as to completely enclose the armature, commutator, brushes, and field coils. The field frame is roughly hexagonal in outline and is made in halves, which are held together by bolts. The two arms *b*, *b* extending from the back of the motor receive one-half the axle bearing, which is in the shape of a split bushing. The axle-bearing caps *c*, *c* are provided with grease boxes, and the grease or oil is fed on the axle by means of pieces of felt from underneath as well as from the

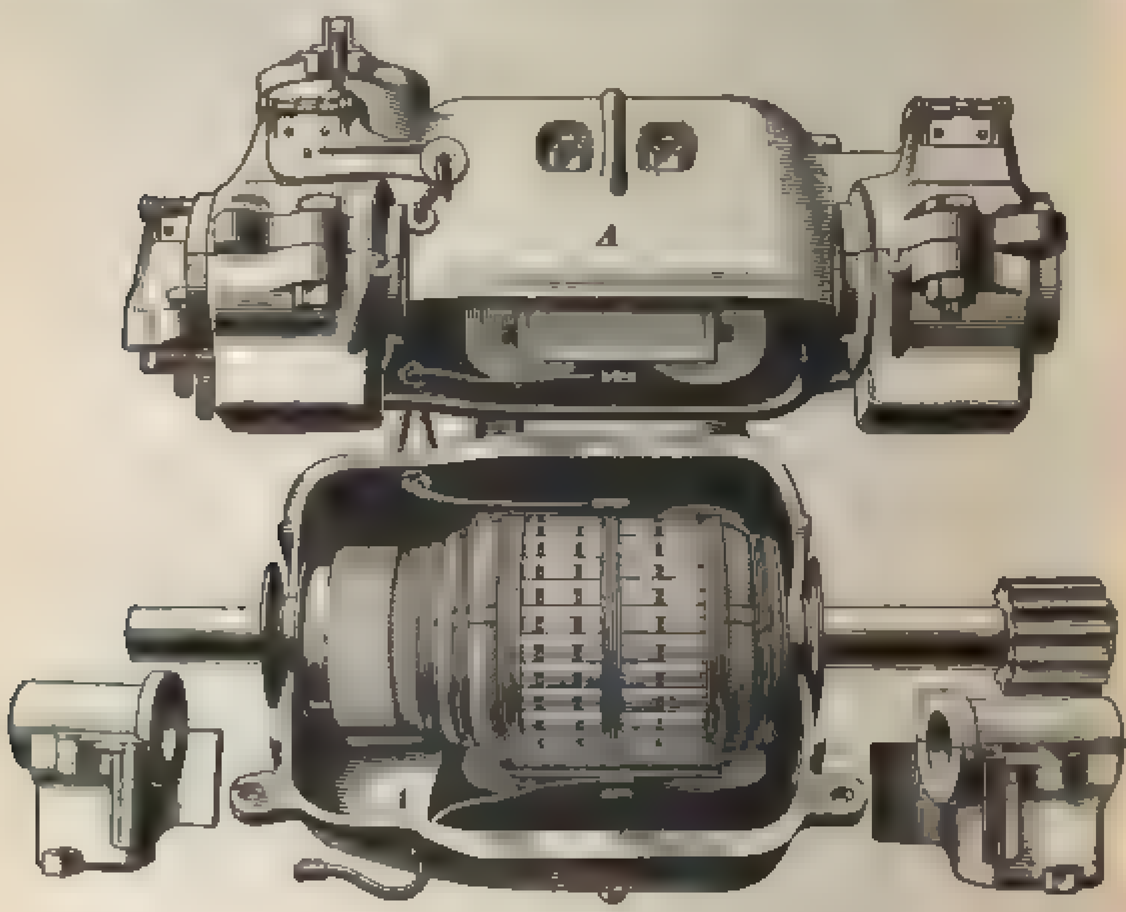


Fig. 6

grease cups on top. The bolts *d*, *d* hold the pole pieces and field coils in place. The removable cover *e* allows access to the commutator and brush holders. The lower armature-bearing caps *f* are separate from the lower half field *A*, and by leaving these caps in position, the lower half field may be swung down, leaving the armature in the upper half, as shown in Fig. 5. By removing the bearing caps, the armature can be lowered with the field, thus leaving the upper field coils and pole pieces exposed, as shown in Fig. 6.

**22. Capacity.**—The G. E. 52 motor has an output of 27 horsepower, based on a run of 1 hour with a 75° C. rise in temperature. The motor is intended for ordinary street-railway work and is not recommended for the heavier kinds of traffic.

**23. Pole Pieces.**—The motor has four poles provided with flanged pole pieces that are laminated; the flanges serve to hold the field coils in place, and the laminations not only do away with a great deal of heat in the pole piece, but from the way in which they are built up they produce a magnetic field that does away with much of the sparking at the brushes. The pole pieces are made of iron plates shaped like the full-line part of Fig. 7 (*b*). In building up the pole piece of these plates every other plate is turned end for end with the result that, along the center part of the pole piece, the plates are close together, but on the horns only half of the plates come out on each side, as shown in Fig. 7 (*a*). This plate construction largely prevents sparking at the brushes, because the thinning out of the metal on the horns of the pole pieces produces a *shaded field* or *fringe*. This shaded field provides a fringe that reverses the current in the coil passing under the brush, and hence brings about the change in the direction of the current with but little sparking.

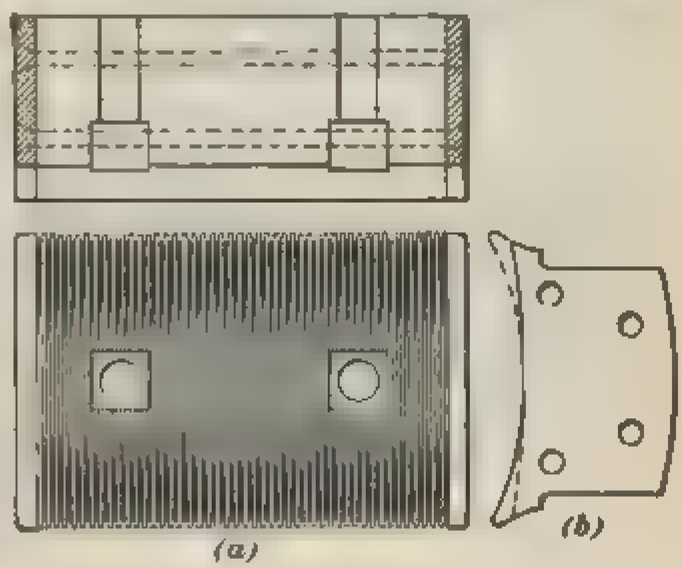

FIG. 7

**24. Field Coils.**—The field coils are wound on forms, and while the asbestos-covered wire is being wound it is treated with a mixture of chalk and japan and afterwards baked. The coils are heavily insulated with tape and insulating varnish and are given a glazed surface that will readily turn off water and prevent moisture from getting in.

**25. Armature.**—Fig. 8 shows a half section of the G. E. 52 armature, and its construction is typical of many of the railway-motor armatures now in use. The core is provided with 29 slots. One side of 6 coils goes into each slot, so that there are 87 coils altogether, and the commutator has 87 bars. The coils are bunched in groups of three, one side of one bunch going into the bottom of a slot, and one side of another into the top of the same slot. In Fig. 8, *a a* is the laminated armature core and

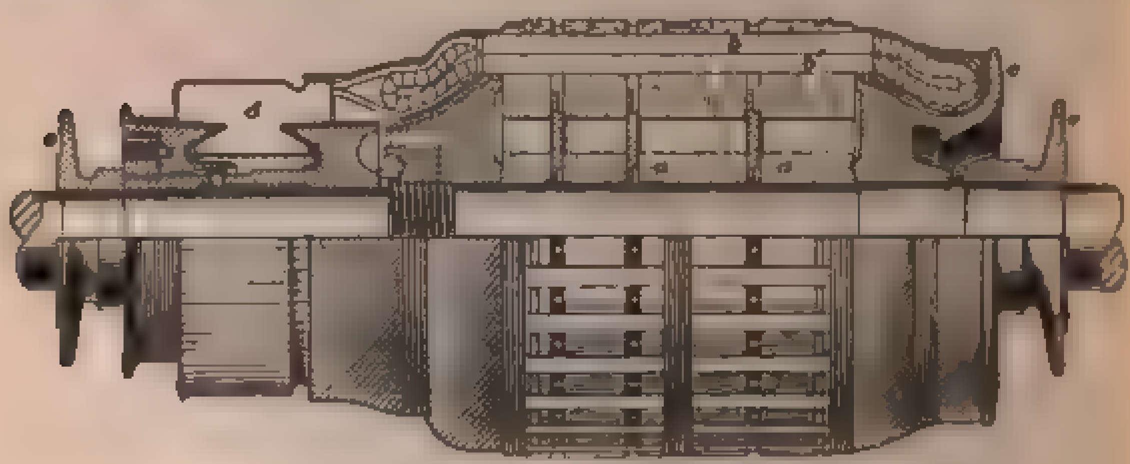

FIG. 8

*b*, *b'* the upper and lower halves of two coils lying in the same slot. The ends of the coils, where they project from the core, are supported and protected by the end shield *c*. The leads from the coils are connected to the commutator bars *d*, which are mounted as shown. The flanges *e*, *e* are for preventing grease and oil working their way into the armature. The bearings are so arranged that any oil getting on *e e* drops through an opening to the street.

**26. Brush Holders.** Railway-motor brush holders are fixed permanently at the neutral point and are not arranged so that they can be shifted, as is the case with many other direct-current machines. The reason for this is twofold: In the first place, the motor has to run in either direction; and in the second place, the variations in load are so sudden that any brush-shifting arrangement is out of the question. The brushes are, however, mounted so that

they can be moved radially toward the center of the commutator as the latter wears away.

Fig. 9 shows the brush holders and brush-holder yoke of the G. E. 52 motor. The yoke *a*, which is made of well-seasoned hardwood treated with insulating material, is bolted to the upper field frame by means of bolts *b*, *b*. The brush holders *h*, *h* are fastened to brass slides on *a* by means of bolts *c*, *c*. All railway motors use carbon brushes; in this case, two brushes $2\frac{1}{4}$ in. × $1\frac{1}{4}$ in. × $\frac{1}{2}$ in. are used in each holder.

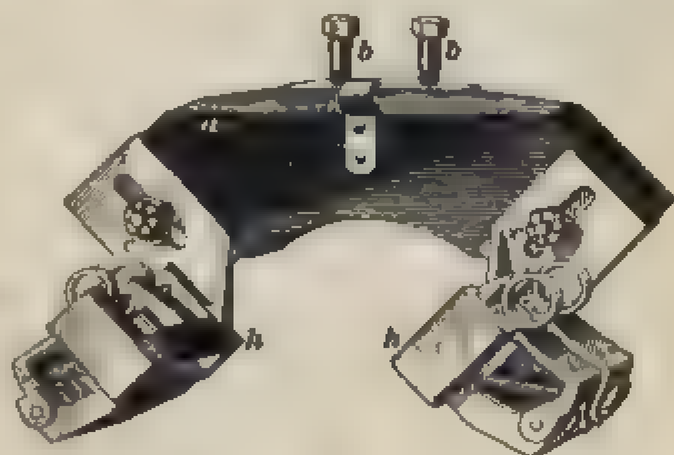

FIG. 9

### G. E. 70 MOTOR

**27.** Figs. 10 and 11 show the G. E. 70 motor, which represents one of the latest types having an output sufficiently large to adapt it for use on suburban cars; its output is 40 horsepower based on the 1-hour rating. The field is made in halves, as shown in Fig. 10, but unlike nearly all the earlier types of motor, the dividing line between the upper half *a* and the lower half *b* is not through the center line of the motor. The upper part lifts off as shown, and dowels *c*, *d* serve to guide it into place when it is lowered into position. The armature bearings are carried in malleable cast-iron frame heads *e*, *f*, Fig. 11, and after these have been unbolted and the top part of the field removed, the whole armature can be lifted out. The object of this design is to make it convenient to work on the motor, from above rather than from a pit underneath, as it is becoming common practice to remove the car bodies from the trucks and work on the motors from above when thorough overhauling is required.

The bearings consist of a bronze lining, or shell, lined with a very thin layer of Babbitt metal that is thoroughly

soldered to the bronze. The Babbitt is so thin that even should the box become hot enough to melt it, the armature will not be lowered sufficiently to rub on the pole pieces. The bronze linings are held securely in the frame heads *e*, *f*, and as the latter have a large bearing surface on the frame and are bolted securely thereto, it is practically impossible for the bearings to get out of line.

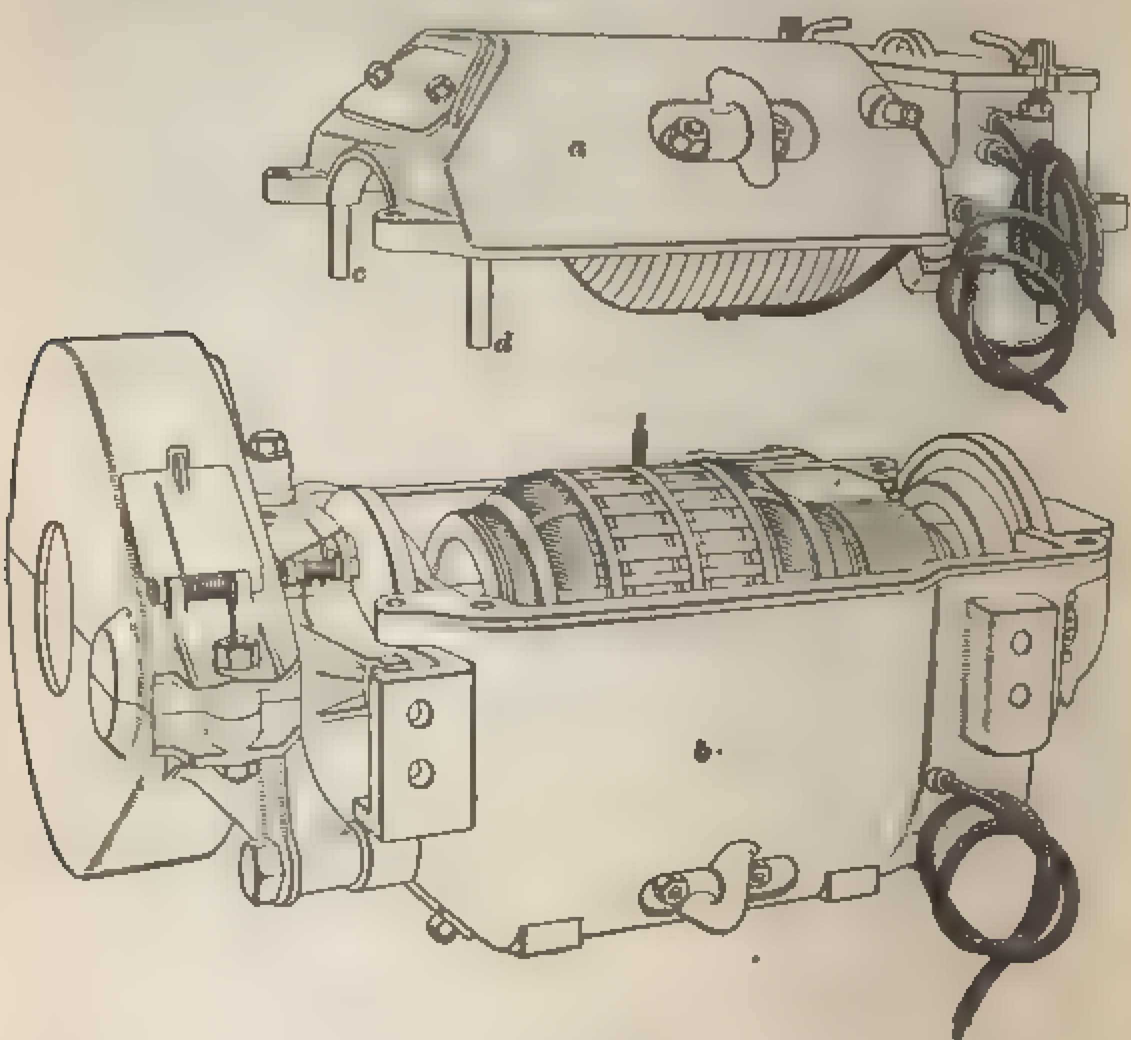


FIG. 10

All bearings are designed for oil lubrication, which is effected in much the same way as on regular car-axle bearings. The linings are in the form of sleeves with openings cut in one side so as to expose the shaft to oily waste that is packed in oil wells, or boxes, cast in the frame heads or in extensions of the brackets that form the axle bearings. The oil boxes are protected by hinged covers held closed by springs. The waste is arranged so that it presses against

the lower part of the shaft and all oil before reaching the shaft must filter through the waste above. If any dirt accidentally gets into the boxes, it is thus prevented from reaching the shaft. This method of lubrication has been found superior to the old method of using grease. Oil deflectors on the armature shaft prevent oil from reaching the armature and commutator, by throwing it into recesses from whence it drops through to the street.

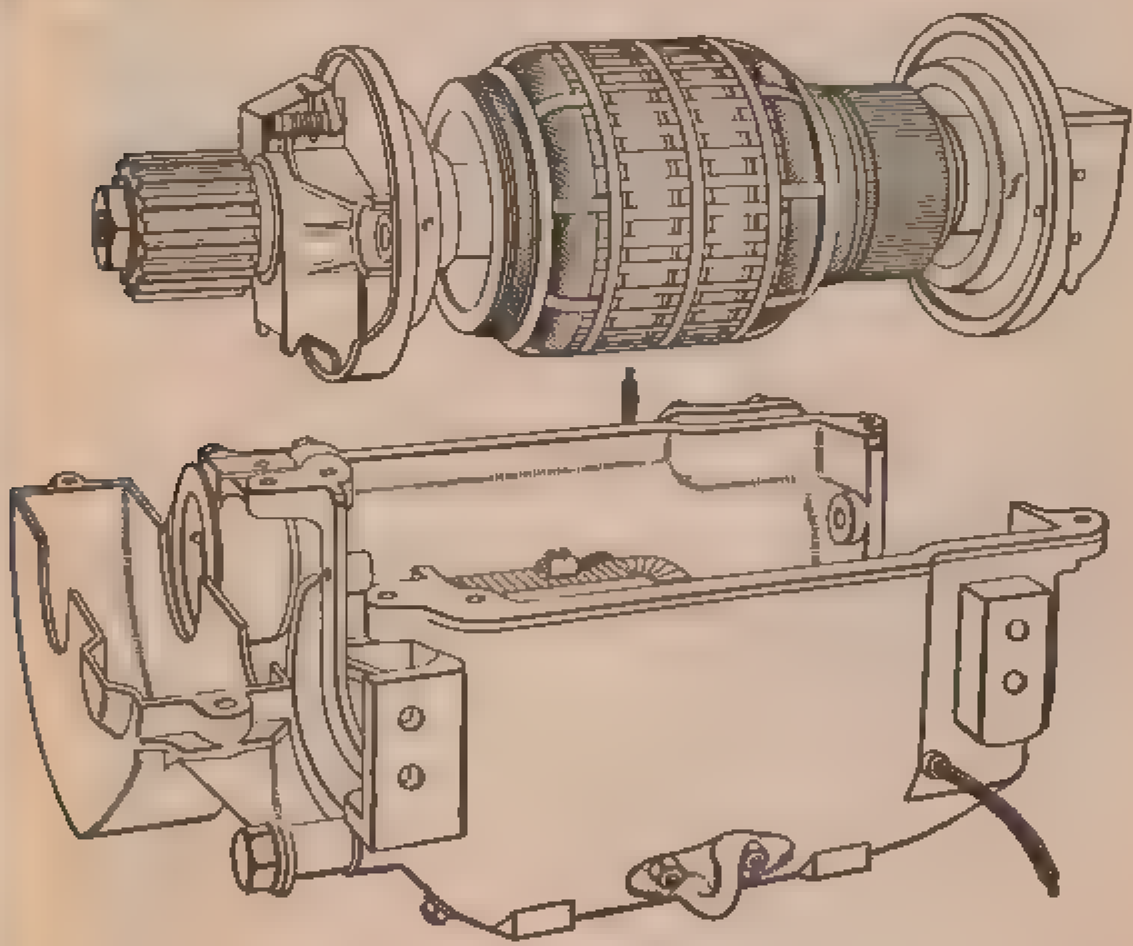

FIG. 11

The four field coils are held in place by the projecting flanges of the laminated pole pieces and, to minimize the chances of abrasion, flanges of steel are placed between the coils and the surfaces with which they come in contact. The coil winding is of the so-called "mummified" type, mica and asbestos being used as insulating materials. Each coil is covered with insulating fabric thoroughly treated with waterproof compound.

### G. E. 69 MOTOR

**28.** This motor, Fig. 12, is of 200-horsepower capacity and represents one of the most powerful types used on elevated and underground roads. Its field frame *a* is of the *box type*, so called because it is cast in one piece, and is

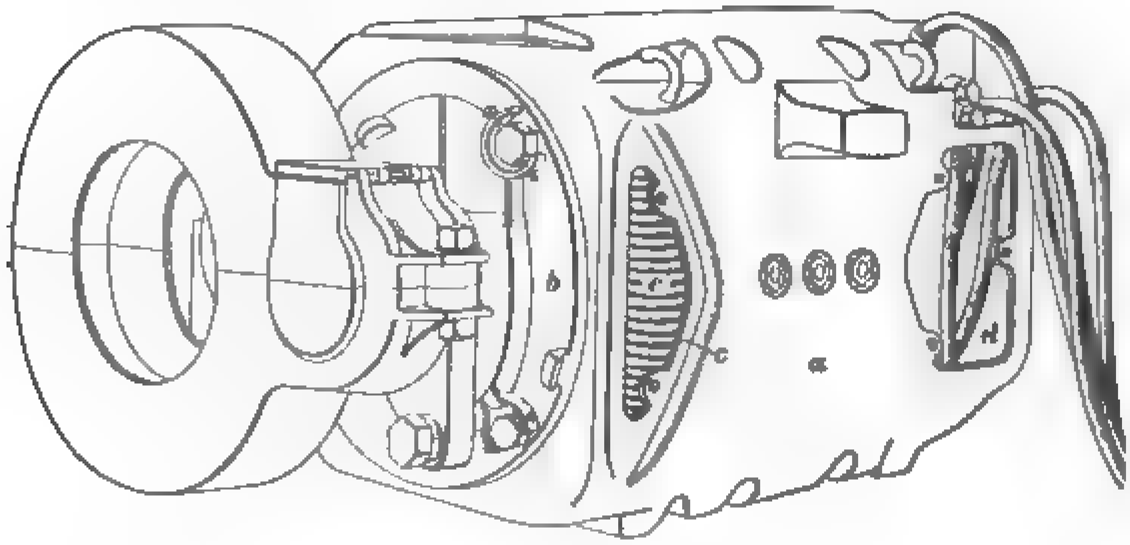

FIG. 12

approximately cubical in outline. The bearings are carried in frame heads, one of which is shown at *b*, in the same way as for the G. E. 70 motor. The heads project within the motor, thus reducing the distance between centers of bear-

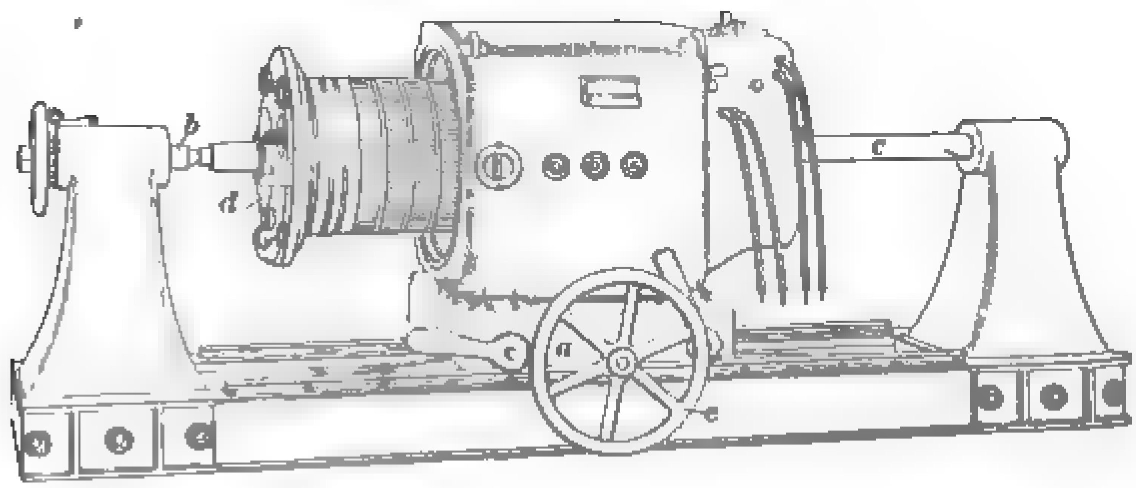

FIG. 13

ings and economizing space, because with these large motors it is difficult to find sufficient space for them between the wheel hubs. Openings *c*, *d* are provided on each side and on top of the motor in order to give access to the inside; under

normal conditions, these openings are covered by plates bolted in place; one of the field coils is shown at *e*. With motors of the box-frame type, the armature is removed endwise by taking out either frame head and sliding the armature through the opening. Fig. 13 shows a stand by means of which armatures can be easily removed from this type of field. The motor is placed on a sliding carriage *a* and the armature held between centers *b*, *c*. After the frame head *d* has been loosened, the field can be moved to the right by turning wheel *e*, thus leaving the armature exposed.

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### WESTINGHOUSE NO. 86 MOTOR

**29.** Fig. 14 is a sectional view of a Westinghouse No. 86 motor, having an output of 200 horsepower based on the 1-hour rating, and intended for the same class of work as the G. E. 69. The arrangement of the inwardly projecting bearings is clearly shown—the bearing at the pinion end projecting under the armature head and that at the other end projecting under the commutator. The field is made in two parts and the four poles are arranged diagonally instead of vertically and horizontally, as in the large General Electric motors in which the box type of frame is used. In nearly all large motors, both armature and field coils are wound with copper strip or bar instead of wire.

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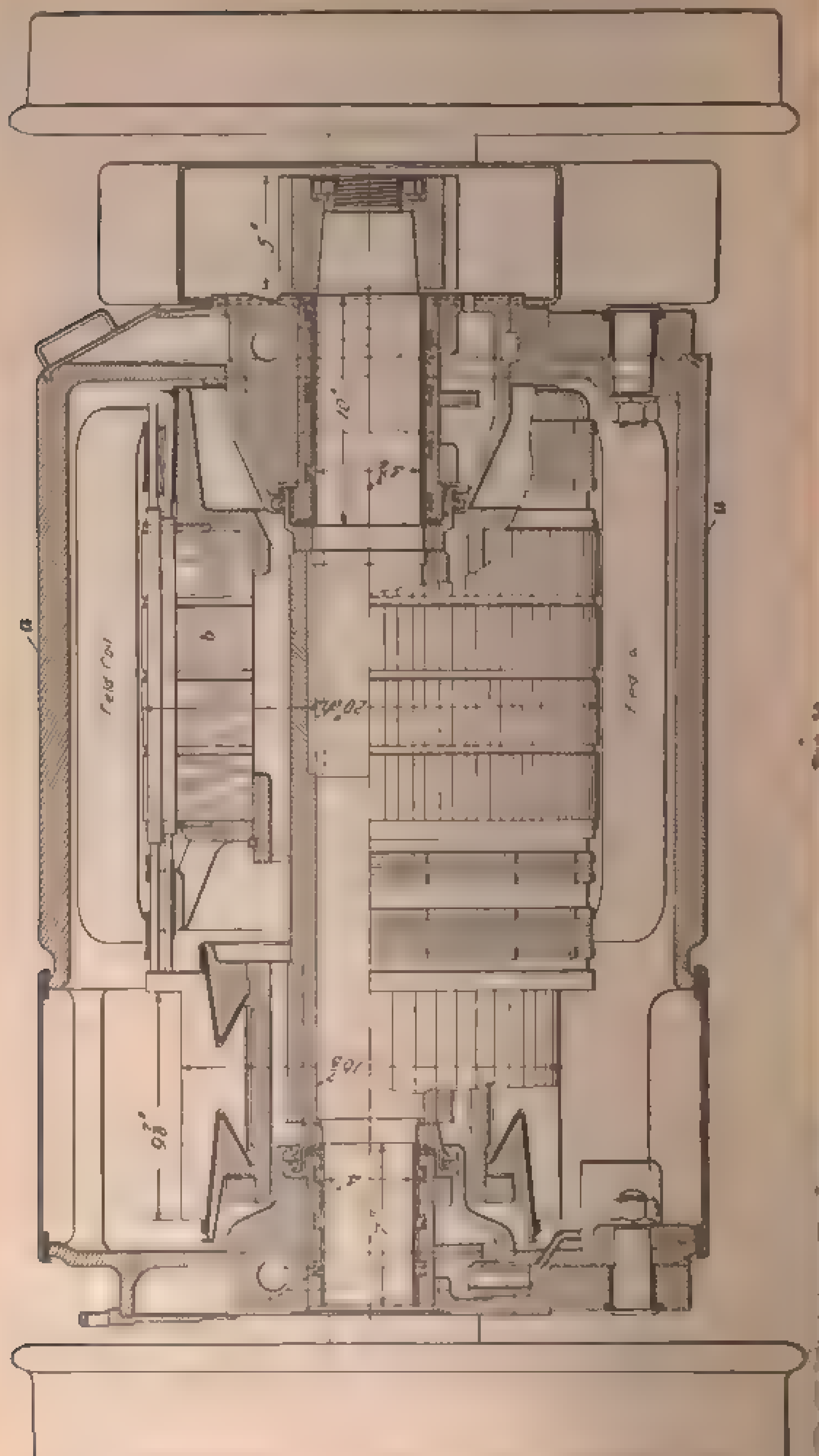
### WESTINGHOUSE NO. 56 MOTOR

**30.** The motor shown in Fig. 15 is typical of a number of Westinghouse motors that vary in size but have the same general construction. This motor, the No. 56, is designed for the heavier kinds of city and suburban traffic, and is capable of carrying continuously a current of 50 amperes at an average pressure of 300 volts. On the basis of a 1-hour rating, its capacity would be about 60 horsepower. In Fig. 15, *A*, *A'* are the top and lower halves of the field frame, which is made of mild cast steel; lid *C* may be thrown back to get at the commutator and brushes. The armature



leads are shown at *a*, *a'* and the field leads at *f*, *f'*; post *g* is used for making the connection to the ground. The lug *l* is for hanging the motor when a nose suspension is used. With a cradle suspension, the side bars pass through the rectangular openings *r* at each end of the motor. The wires

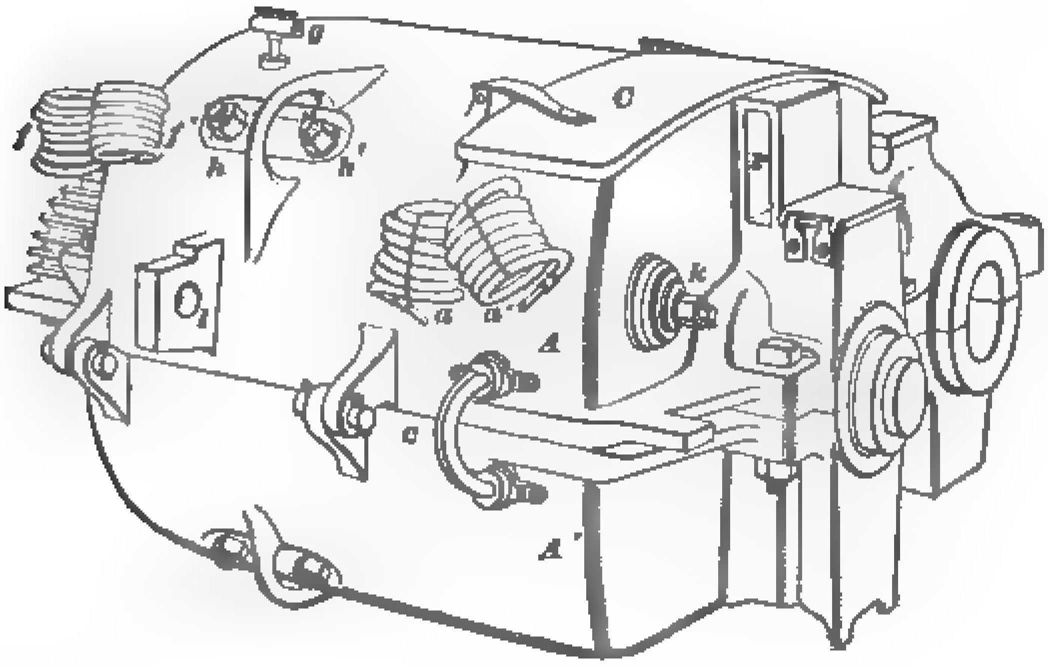



FIG. 15

shown at *c* connect the top and bottom field coils together. The pole pieces are laminated and held in position by the bolts *h*, *h'*, and the armature bearings are so arranged that the armature may be either swung down with the lower half or retained in the upper half.

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## ALTERNATING-CURRENT MOTORS

**31. Alternating-current motors** for railway work have so far been used comparatively little. Both the Westinghouse and General Electric motors are of the series type and their construction and general appearance are on the whole very similar to ordinary direct-current motors; in fact, they will operate on either direct or alternating current. One of the chief points of difference is that the whole magnetic circuit of the alternating-current motor field must be laminated in order to prevent eddy-current loss due to the alternating magnetic flux. The field core is built up of iron

stampings and slipped inside of a housing, so that the outward appearance and general mechanical construction are practically the same as for direct-current motors. The motors also include some special features in design, introduced to prevent sparking at the brushes. In the General Electric so-called compensated motors, the field winding instead of being wound on definite projecting poles, is distributed in slots in a manner similar to the field winding of an induction motor. The compensating winding counteracts the effects of armature reaction and prevents sparking. In the Westinghouse motors, the field coils are wound on projecting pole pieces. In both types of motor, the construction of armature and commutator is practically the same as for direct-current motors.

It is much easier to build satisfactory alternating-current motors for low voltage than for high voltage, and as the alternating current is easily stepped down to any voltage desired, they are usually wound for 200 to 225 volts, instead of 500 volts. When it is desired to operate the motors on 500-volt direct current, as well as on alternating current, they are connected permanently in series, in pairs. The standard frequency is 25 cycles per second, since a low frequency is necessary for satisfactory operation of motors of this type.

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## MOTOR LUBRICATION

**32.** The question of proper lubrication for railway motors is an important one. Insufficient lubrication not only causes a waste of power but it may lead to much damage to the equipment by allowing the bearings to wear so as to let the armature down on to the pole pieces. In the older motors grease was used as a lubricant, but it is fast being superseded by oil. Grease does not feed down until the bearing becomes warm enough to melt it, whereas oil furnishes continuous lubrication. On many of the later motors, lubrication is effected by means of wool waste saturated with oil, as described in connection with the G. E. 70 motor, this method having proved very simple and efficient.

In order to allow oil lubrication on old motors provided with grease cups, a number of oil lubricators have been designed. In some cases, these have not proved satisfactory because the oil fed down while the cars were standing in the barn at night, thus causing much waste. Fig. 16 shows an oil lubricator, made by the Standard Automatic Lubricator Company, for attaching to motors built for grease lubrication. The cast-iron oil cup *a*, provided with a lid *b* normally held closed by a spring, is mounted on top of the grease cup; the cover on the old cup is removed and *a* is held in place by the projecting lug *c*; the lower part *d* projects into the grease cup, which is filled with loosely packed waste. The opening in *d* is closed by a ball valve *e* held against its seat by a spring *f*, the tension on which is adjusted by nut *g* so that no oil can pass out while the car is standing still. When the car is in motion, the vibration and knocks to which it is subjected unseat *e* so that oil can flow on to the waste. Thus, there is no waste of oil while the car is standing still, but the oil feeds as long as the car is in motion. For shafts less than $2\frac{3}{4}$ inches diameter, a feed of $\frac{1}{8}$ inch of oil in the cup should be sufficient for 100 miles of car travel; for larger shafting a feed of about $\frac{3}{16}$ inch should be allowed.

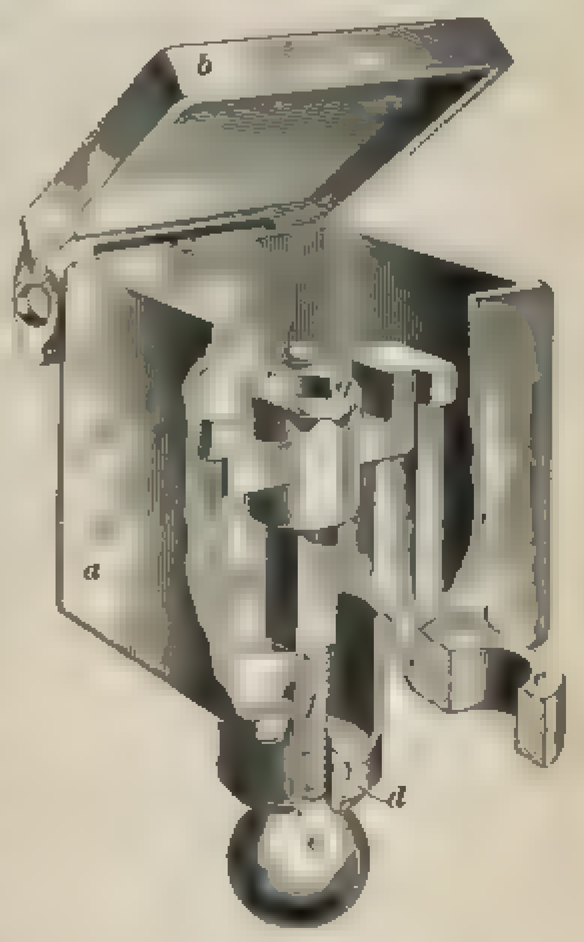
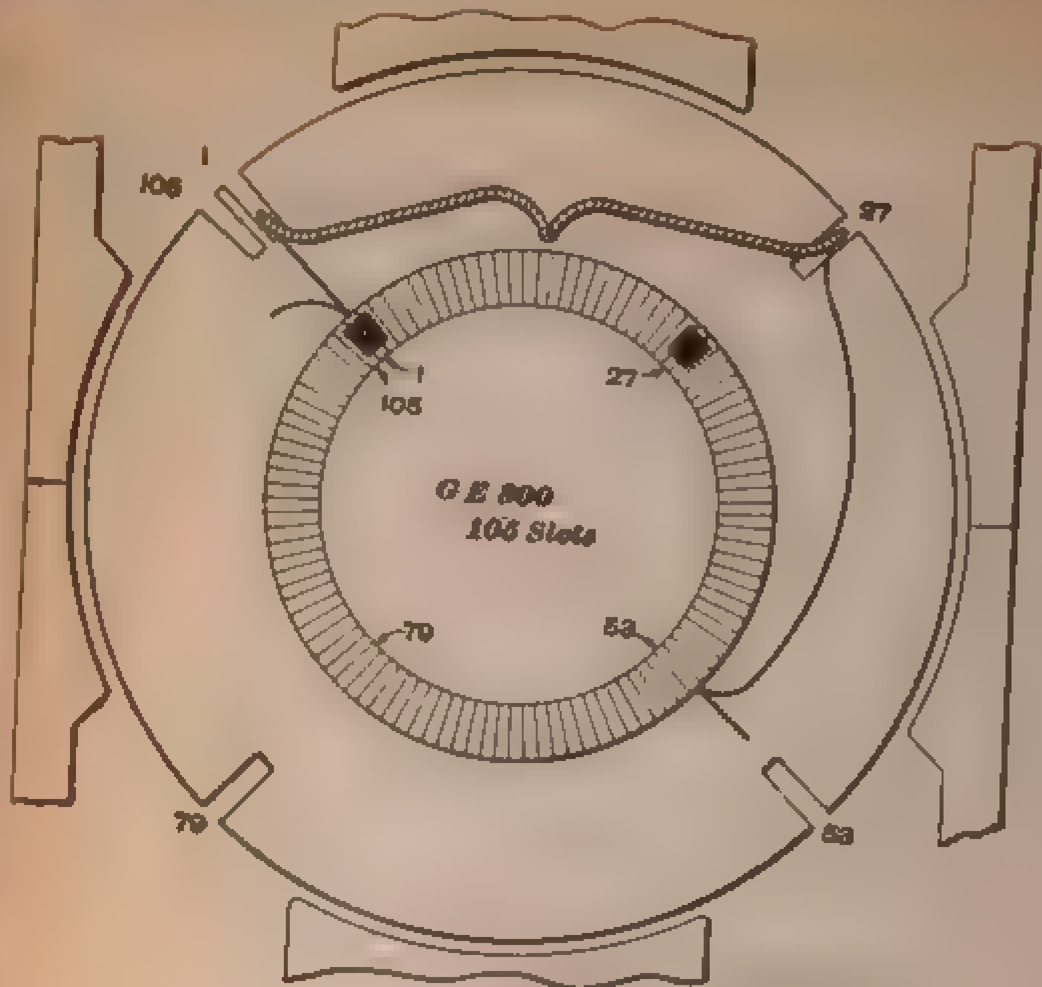


FIG. 16

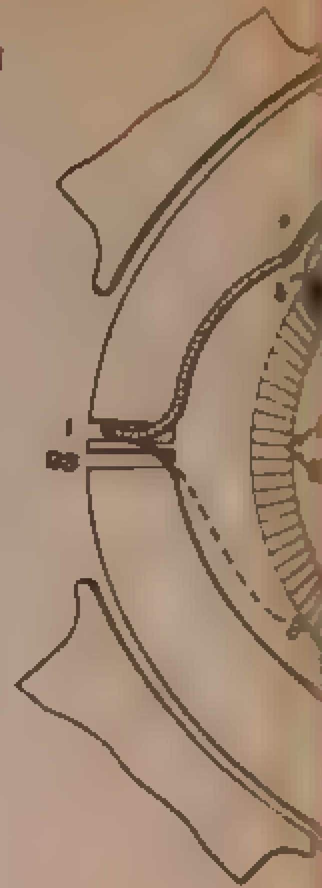
## ARMATURE WINDINGS FOR RAILWAY MOTORS

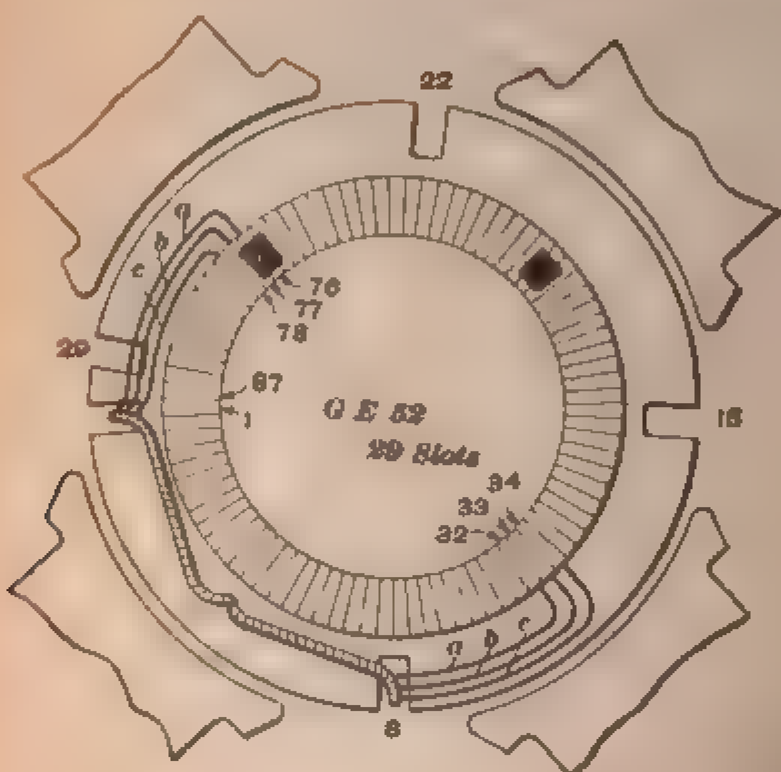
**33.** The armatures of railway motors are nearly always of the four-pole drum type; on some of the older motors ring windings were used, but these are now obsolete. The coils are wound on forms, and after being covered with insulating tape are placed in the slots on the core. They are always arranged in two layers so as to cross each other at the ends without interfering, and are connected to the commutator to form a two-circuit or series winding. The total number of coils must fulfil the relation $C = \frac{p}{2} \times Y \pm 1$, where $C$ is the number of coils, $p$ the number of poles, and $Y$ the pitch of the coil terminals on the commutator; thus, if one end of a coil connected to bar 1, and the other to bar 53, the pitch $Y$ would be $53 - 1 = 52$. Since in nearly all railway motors $p = 4$, $\frac{p}{2} = 2$ and $\frac{p}{2} \times Y$ is an even number; hence, $\frac{p}{2} \times Y \pm 1$ is an odd number no matter what the value of $Y$ may be.

In many armatures, two or more coils are taped together to form a winding element and the number of coils may therefore be different from the number of slots. If there are 2 or 4 coils per slot, the total number of coils will be even no matter what the number of slots may be, and the winding will therefore not connect properly. For example, take the Westinghouse 12A armature, Fig. 18; there are 47 slots and each winding element consists of 2 coils taped together; hence, there are 94 coils. But 94 coils will not fulfil the relation $C = \frac{p}{2} \times Y \pm 1$, because the number of coils must be odd; hence, one coil is cut out by cutting off its terminals and taping the ends over. This leaves 93 coils to be connected and the dead, or "dummy," coil is left in the armature simply to maintain the mechanical balance. These so-called dummy coils are found in a number of armatures, but the later motors are generally designed so as to avoid them.

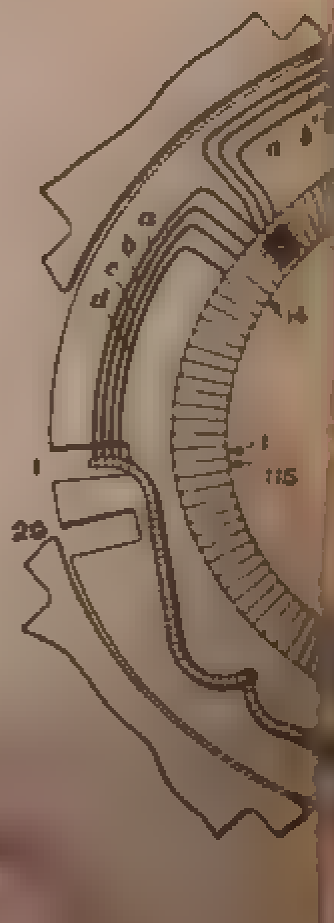


1
106
27
105
G E 800
105 Slots
79
53

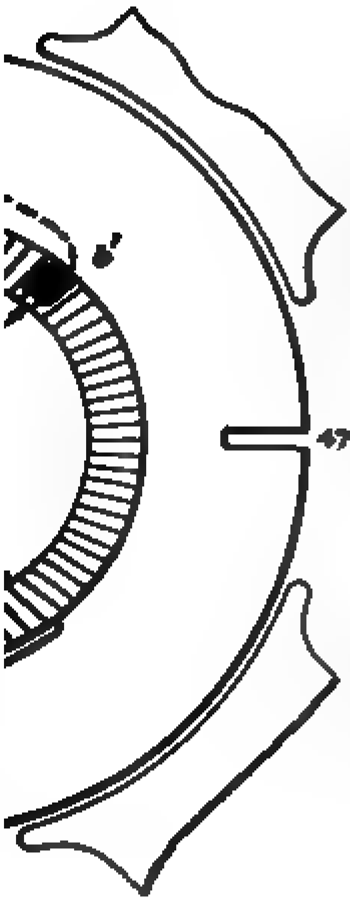



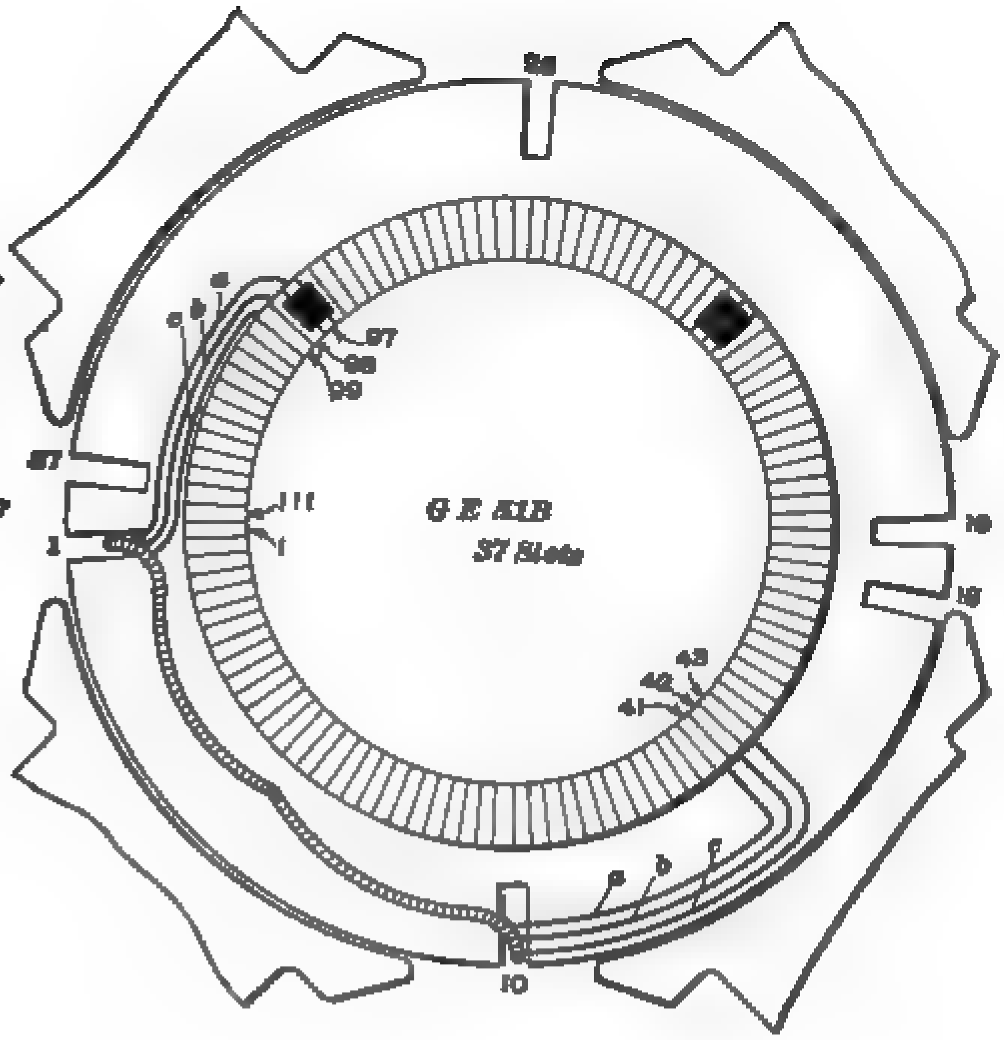


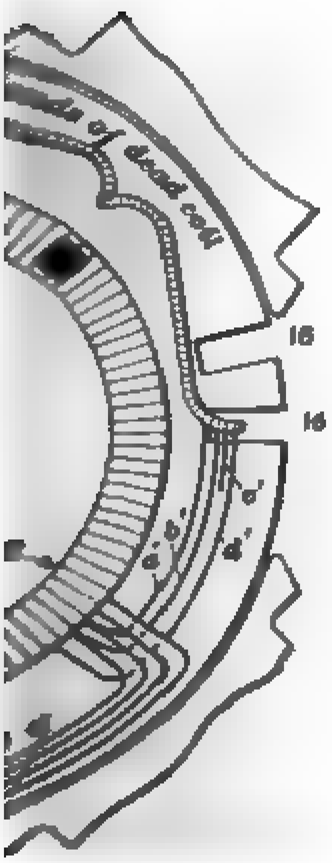
22
a
b
c
76
77
78
29
67
1
G E 52
29 Slots
16
34
33
32
8

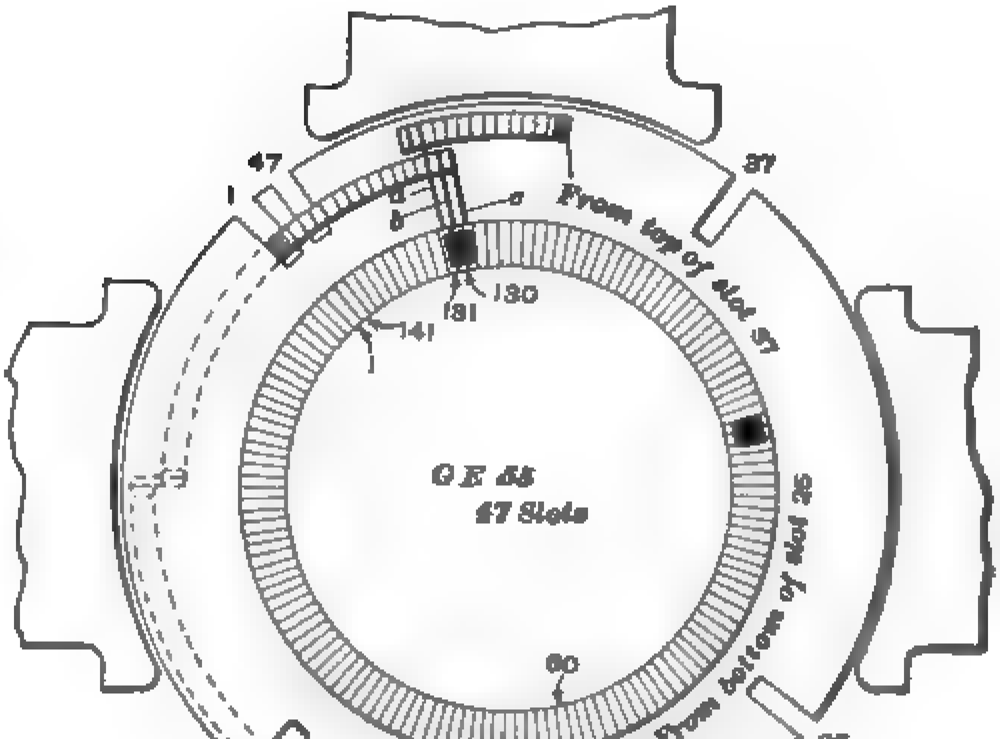



a
b
c
d
14
1
115
29


47


26
37
1
47
19
18
10
97
98
99
111
G E 51B
37 Slots
41
42
43
a
b
c


ends of dead coil
16
15


47
1
37
From top of slot 37
130
131
141
From bottom of slot 25
60
25
13
a
b
c

**34.** The series winding has many advantages for railway-motor work, not the least of which is that it requires only two brushes; if four brushes were used, as would be necessary with a parallel winding, the lower brushes would be very hard to get at. Another advantage is that uneven centering of the armature due to wear in the bearings or other causes does not produce an unbalanced electrical condition, as might be the case with a parallel-wound armature not provided with equalizing rings.

It is not possible to show here all the connections for standard railway-motor armatures. Figs. 17 and 18 show a number of the most common ones, and if these are thoroughly understood there will be no difficulty in following out the connections of other armatures. For convenience in indicating the connections, a slot on the core is taken and called *slot No. 1*, then the commutator bar directly in line with slot 1 is marked No. 1. Practice varies as to the methods of numbering and counting off the bars, but the three main things to be considered are: the throw of the coil leads, the number of bars between leads, and the spread of the coils on the core. The throw of the leads determines the location of the brushes with respect to the pole pieces. For example, in the G. E. 800 armature, Fig. 17, one coil lead is brought straight out to the commutator bar because the pole pieces are arranged vertically and horizontally and it is desired to have the brushes located on the diagonals as shown. In the Westinghouse No. 3, Fig. 18, both coil leads are given a throw so as to bring the brushes as shown, the pole pieces being located on the diagonal; for example, the lead coming from the bottom of slot 1 is connected to bar 84, found by counting off thirteen to the left from bar 1. In the G. E. 55, the two throws are unequal, thus bringing the brushes into a position at a slight angle from the vertical and horizontal.

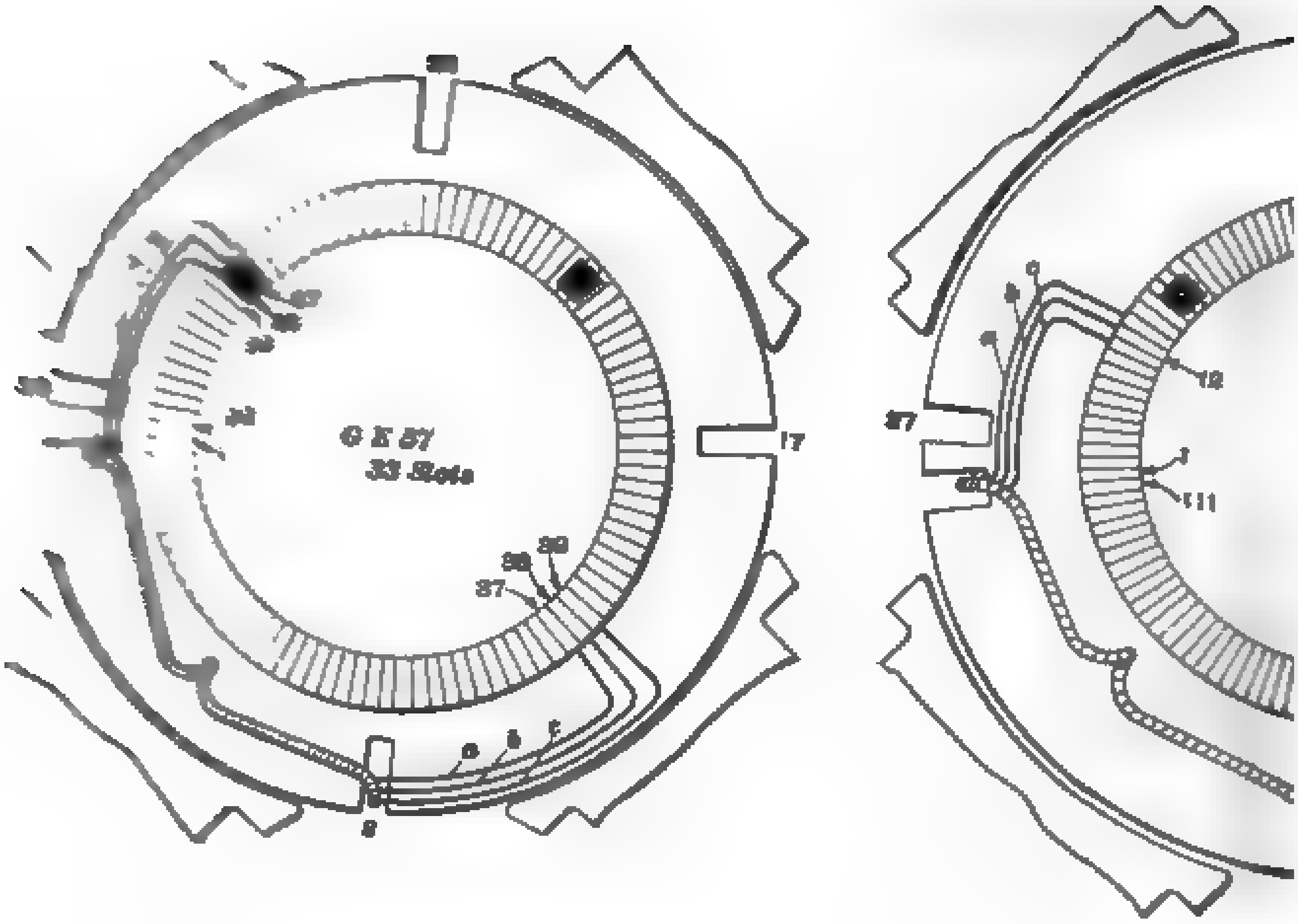
**35.** G. E. 800.—This armature, Fig. 17, has 105 slots and 105 coils. The coil pitch is 26 slots; i. e., the two sides of a coil drop into slots 1 and 27. The coil terminals have a

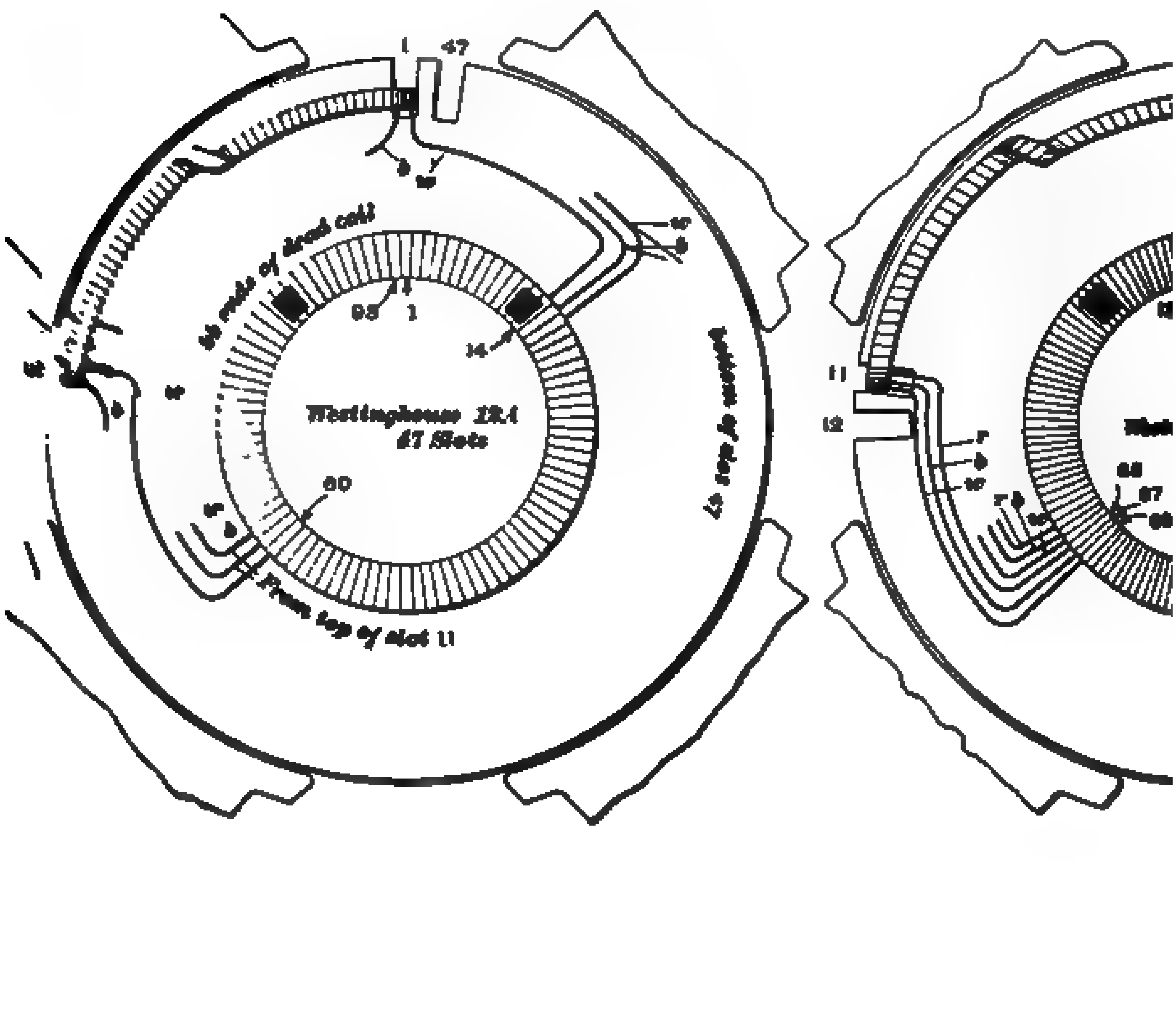
pitch of 52 bars on the commutator, or if one end connects to bar 1, the other connects to $1 + 52$ or bar 53. Thus, $Y = 52$, $105 = 2 \times 52 + 1$, and the requirements for a two-circuit winding are fulfilled. The second coil would be dropped into slots 2 and 28, and its terminals connected to bars 2 and 54. After the first coil has been placed in position and its leads connected the others follow in rotation, so that in nearly all the diagrams only one coil is shown.

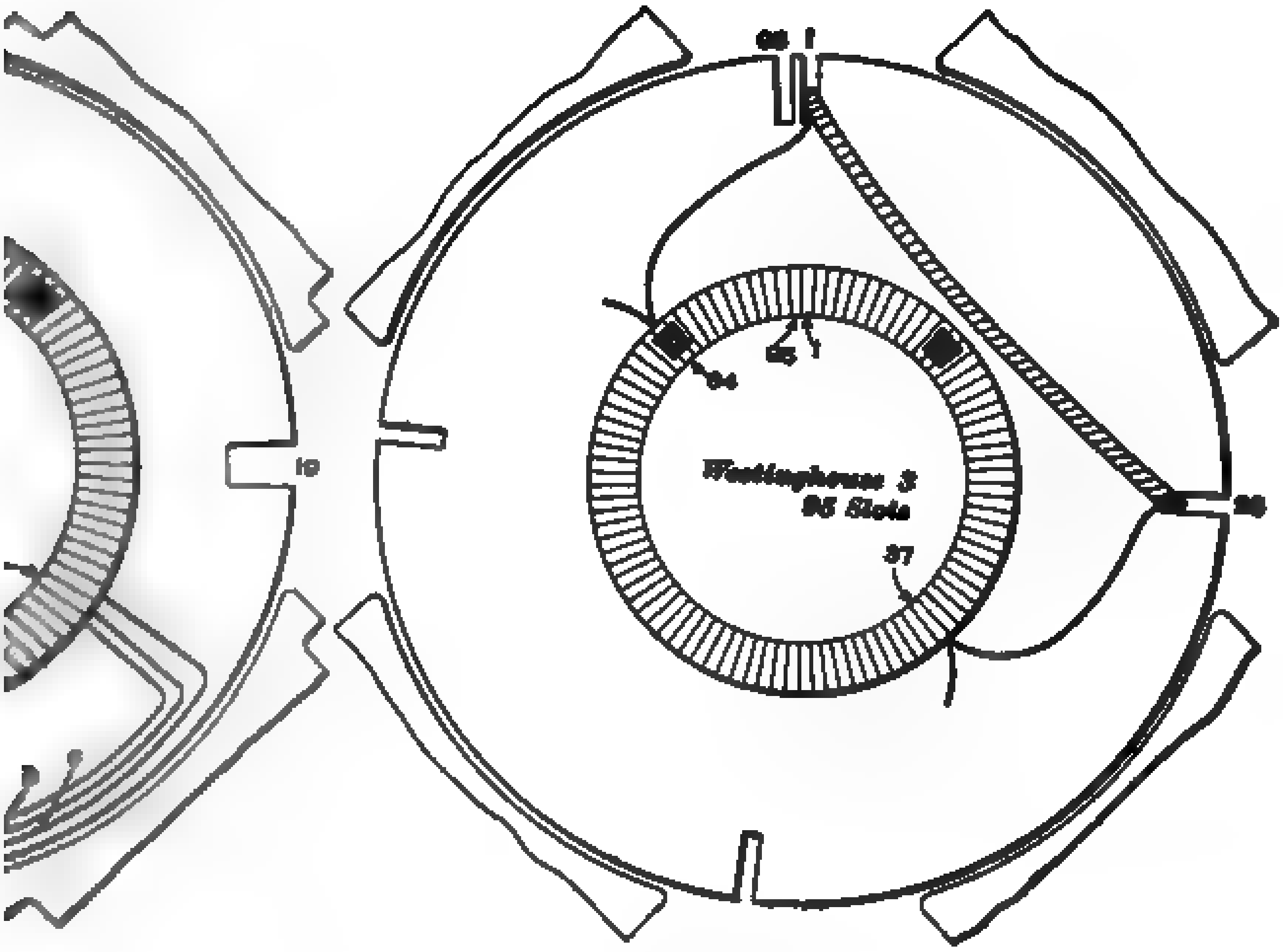
**36. G. E. 1,000.**—The G. E. 1,000 armature, Fig. 17, has 93 slots and 93 coils having a pitch of 23 slots on the core. The pitch of the coil terminals on the commutator is 42 bars. The coil lead *a b* is thrown back as shown, but in many cases it is taped in with the coil and appears as a lead coming out at the bend *c* of the coil and is therefore connected to the bar directly opposite the bend. This armature could also be connected as shown by the dotted lines, thus making the coil leads more symmetrical. With the same field connections, an armature connected as shown by the dotted lines would run in the opposite direction from one connected as shown by the full lines.

**37. G. E. 51B.**—The G. E. 51B armature, Fig. 17, has 37 slots, 3 coils per slot, or 111 coils. This is an example of an armature where each winding unit consists of 3 coils taped together. The pitch on the armature core is 9, the coils dropping into slots 1 and 10. The corresponding coil leads are marked *a*, *b*, *c*, and the throw is the same at each side of the coil, thus bringing the brushes opposite the center of the pole pieces. The pitch of the coil leads on the commutator is 55. The commutator pitch $Y$ in any of the diagrams can be found as follows: Take, for example, the G. E. 51B, and call the bar to which the upper middle lead *b* is connected bar 1, instead of 98 as marked. Then count around under the coil until the bar to which lower lead *b* connects is reached. This will be bar 56, and the commutator pitch $Y$ is therefore $56 - 1 = 55$.

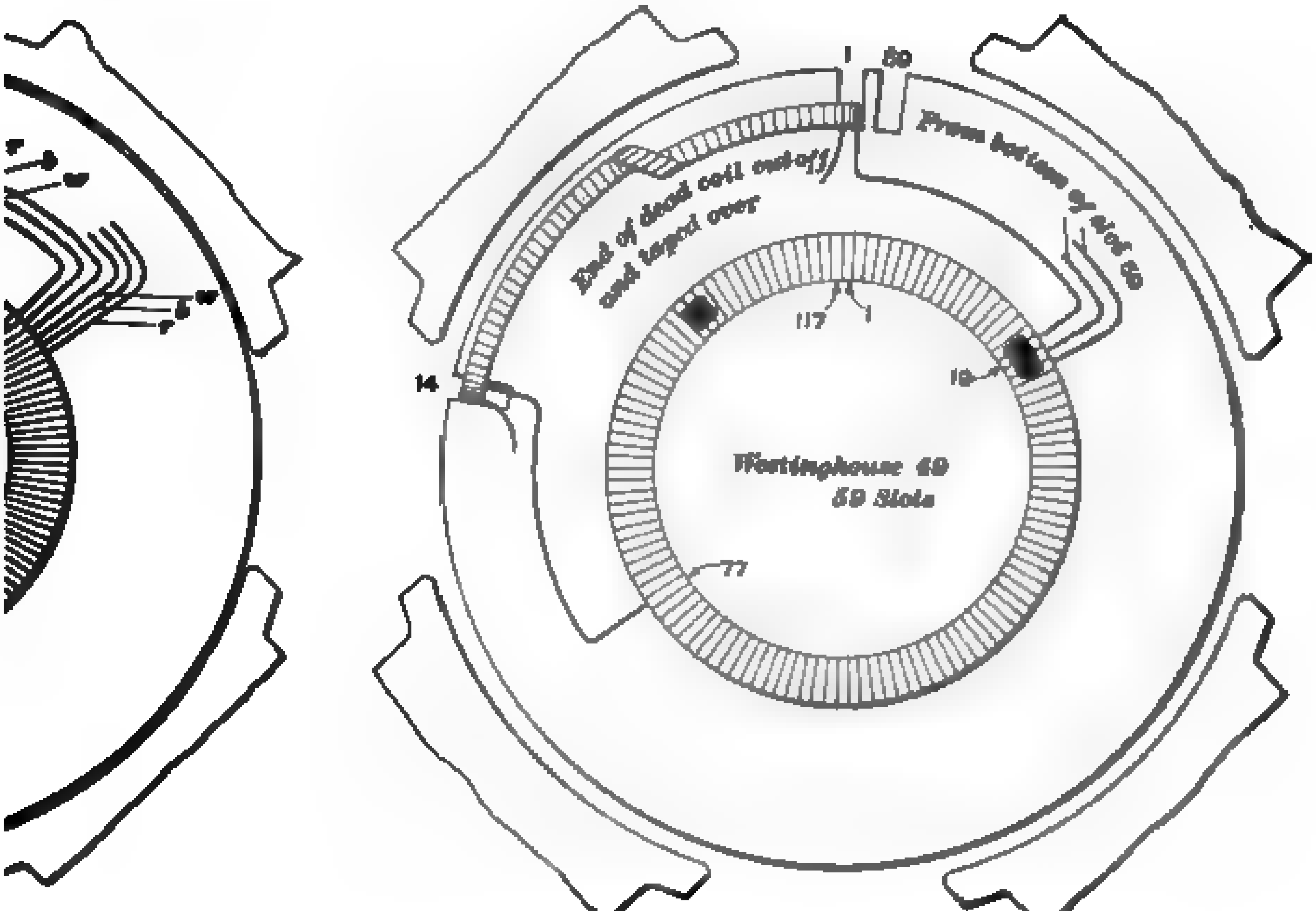
**38. G. E. 52.**—The G. E. 52 armature, Fig. 17, has 29 slots: 3 coils per slot, or 87 coils; the coils span 7 slots.


G E 57
33 Slots
17
27
12
11


1
47
to ends of dead coil
Westinghouse 12A
47 Slots
14
30
From top of slot 11
11
12



1
19
94
95
1
Westinghouse 3
95 Slots
37

1
59
From bottom of slot 59
End of dead coil cut-off
and taped over
117
1
14
19
Westinghouse 49
59 Slots
77

Each winding unit consists of 3 coils taped together and corresponding terminals of the 3 coils are lettered *a*, *b*, *c*. The span, or pitch, on the commutator is 43, and $87 = 2 \times 43 + 1$.

**39.** G. E. 54.—The G. E. 54 armature, Fig. 17, has 29 slots; 4 coils per slot, or 115 coils. The coils have a pitch of 7 slots on the core. This is an example of a winding where one coil has to be left dead in order that the coils may connect up to form a two-circuit closed-coil winding. If all the coils were used, there would be $29 \times 4 = 116$, and this number would not fulfil the relation $C = \frac{p}{2} Y \pm 1$. If an attempt were made to use 116 coils, the winding would close on itself after progressing once around the commutator. By cutting out 1 coil and using a pitch of 57 on the commutator, we have $115 = 2 \times 57 + 1$ and the winding requirements are fulfilled. Fig. 17 shows one of the regular winding units in place and also the unit with 1 coil cut out. Usually in winding armatures where there is a dummy coil, the first coil put on contains the dummy, though it makes no difference which coil is selected.

**40.** G. E. 55.—This motor is of large size and has an armature wound with copper bar. The field frame is of the box type, and in order to bring the brushes opposite the opening in the frame the leads of the coil connections, Fig. 17, are different on the two ends. The armature has 47 slots with 3 coils per slot, each coil being a single loop of copper bar. The sides of a winding unit have a pitch of 12 slots on the armature core.

**41.** G. E. 57.—The G. E. 57 armature, Fig. 18, has 33 slots, 3 coils per slot, or 99 coils. The winding units have a pitch of 7 slots; i. e., the unit is placed in slots 1 and 8. The pitch on the commutator is 49, and $99 = 2 \times 49 + 1$.

**42.** G. E. 67.—The G. E. 67 armature, Fig. 18, has 37 slots, 3 coils per slot, or 111 coils. The coil pitch on the armature core is 9, and the pitch of the coil leads on the commutator is 55.

**43. Westinghouse No. 3.**—The Westinghouse No. 3 armature, Fig. 18, has 95 slots and 95 coils. The pitch of coils on armature core is 24. The pitch of coil leads on commutator is 48, and 95 = 2 × 48 − 1.

**44. Westinghouse No. 12 or 12A.**—The Westinghouse No. 12 or 12A armature, Fig. 18, has 47 slots, 2 coils per slot, or 93 coils. The pitch of the coils on the core is 11 slots. This armature has a dummy coil, so that the number of coils to be connected is one less than twice the number of slots. In order to distinguish the corresponding ends on each winding unit, they are marked white and black, as indicated by the letters *w* and *b*.

**45. Westinghouse No. 38 or 38B.**—The Westinghouse No. 38 or 38B armature, Fig. 18, has 45 slots, 3 coils per slot, or 135 coils. The coil pitch on the armature core is 10, the coils dropping into slots 1 and 11. The coil terminals are marked red, black, and white, as indicated by the letters *r*, *b*, and *w*.

**46. Westinghouse No. 49.**—The Westinghouse No. 49 armature, Fig. 18, has 59 slots, 2 coils per slot, or 117 coils. This armature has a dummy coil, otherwise the number of coils would be even and the armature would not connect up. The coil pitch on the armature core is 13.

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## FIELD COILS

**47.** One of the most common sources of trouble in connection with street-railway motors is wrongly placed or connected field coils. Few have any idea of the great amount of trouble a wrongly connected field coil may cause; its effect is felt long after the trouble has been found and removed. It not only injures itself, but it injures the other field coils and the armature. The armature probably heats to such an extent that the commutator connections become unsoldered and the fields gradually bake inside. The chances are that before the trouble is discovered and removed there may be grounded brush holders, armatures, or

fields, due to the current jumping across to the frame of the motor, because the weak fields in the first place cause poor commutation, and in the second place reduce the counter E. M. F. and allow more current to flow than the brushes can stand. It is safe to say that one-half of the trouble on cars turned in for blowing fuses can be traced directly or indirectly to defects in the field coils.

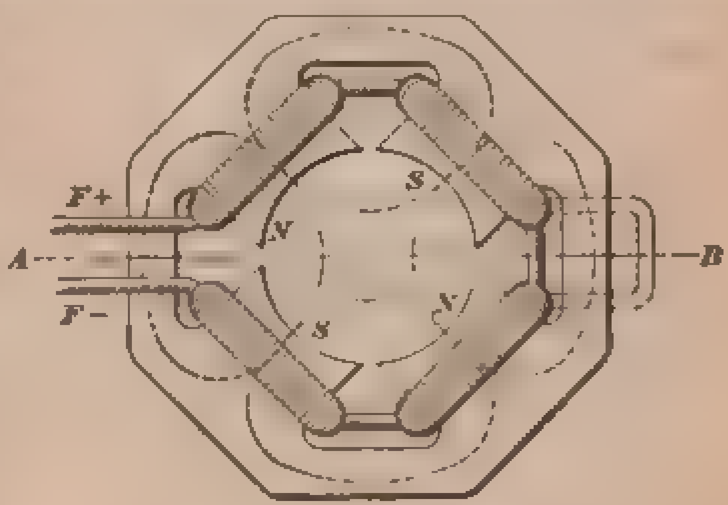



Fig 19

Fig. 19 shows a section through a four-pole motor with a coil on each pole; the coils are so connected that the pole pieces alternate in polarity. In Fig. 20, the coils are not shown but the top left-hand coil is supposed to be connected incorrectly, with the result that the lines of force are very much twisted out of their path. However, it will be noticed that two sides of the four-sided figure made by the path of the lines of force can still be seen. Part of the armature is therefore effective, and the car will run on the faulty motor, but the brushes will spark badly, and there will be great consumption of current. The large current soon roasts the insulation on the coils, thus short-circuiting the turns and making matters still worse.

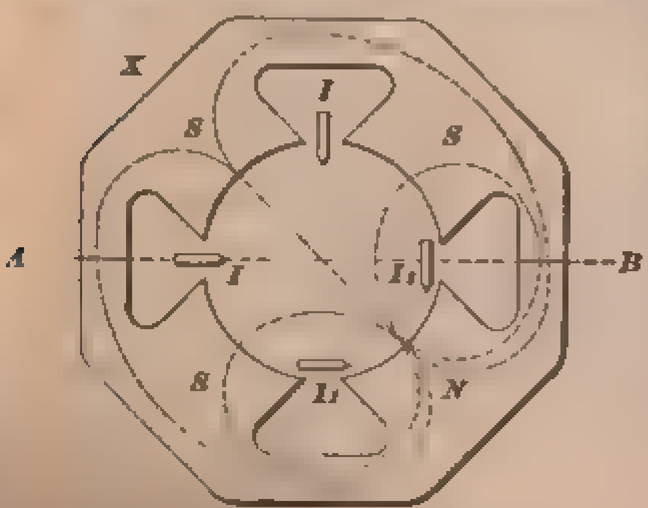



Fig 20

Even if field coils are not incorrectly connected, they will in time bec... roasted, especially if the motors are worked ... ...ome so charred as to allow

current to pass from turn to turn without encircling the pole piece, thus decreasing the magnetizing power of the coil. The field coils should therefore be tested from time to time to make sure that there is no short-circuiting due to roasting or other causes. In order to permit such tests to be carried out quickly, a number of special testing instruments have been devised. If a coil becomes short-circuited, its resistance measured between terminals will be lower than normal. Some of the field-coil testing instruments are a modified form of Wheatstone bridge, by which the resistance of a coil can be rapidly measured and compared with that of a coil known to be all right.

**48. Conant Field-Coil Tester.**—Railway-motor field coils are wound with a few turns of heavy wire; hence, their resistance is very low and it is difficult to make accurate resistance measurements with any form of bridge that can be handled quickly in a motor repair shop. The inductance of a field coil, as compared with a good coil, is more easily determined, and any change in the effective number of turns has a marked effect on the inductance, because, other things being equal, the inductance varies as the square of the number of turns. In the field-coil tester of Mr. R. W. Conant, the inductances of two field coils are balanced against two adjustable inductances in about the same manner as resistances are balanced in a Wheatstone bridge. The principle of the instrument will be understood from Fig. 21. *A* and *B* are two coils, one of which *A* is known to be all right, while *B* is to be tested. Connection is made to the cable leads by means of points *f*, *f* that are worked through the rubber insulation until they make contact with the strands of wire; in this way temporary connections are quickly made. Two coils *a*, *b* with iron cores that can be moved into or out of them are connected in series, as shown. The coils *a*, *A*, *b*, *B* correspond to the four arms of a Wheatstone bridge, but instead of balancing the resistances of *a* and *b* against those of *A* and *B* their inductances are balanced by varying the inductances of *a* and *b*. If, for example, the iron core $a_1$ is

moved into $a$, the effect is to increase the inductance of $a$, and vice versa. A few cells $c$ send a current through the coils, and in order that induced E. M. F.'s may be set up, the current is interrupted by a clockwork mechanism $d$ that drives a toothed contact wheel. A telephone is connected at $e$ in order to indicate when the instrument is balanced. Suppose, for the present, that $A$ and $B$ are perfect coils and

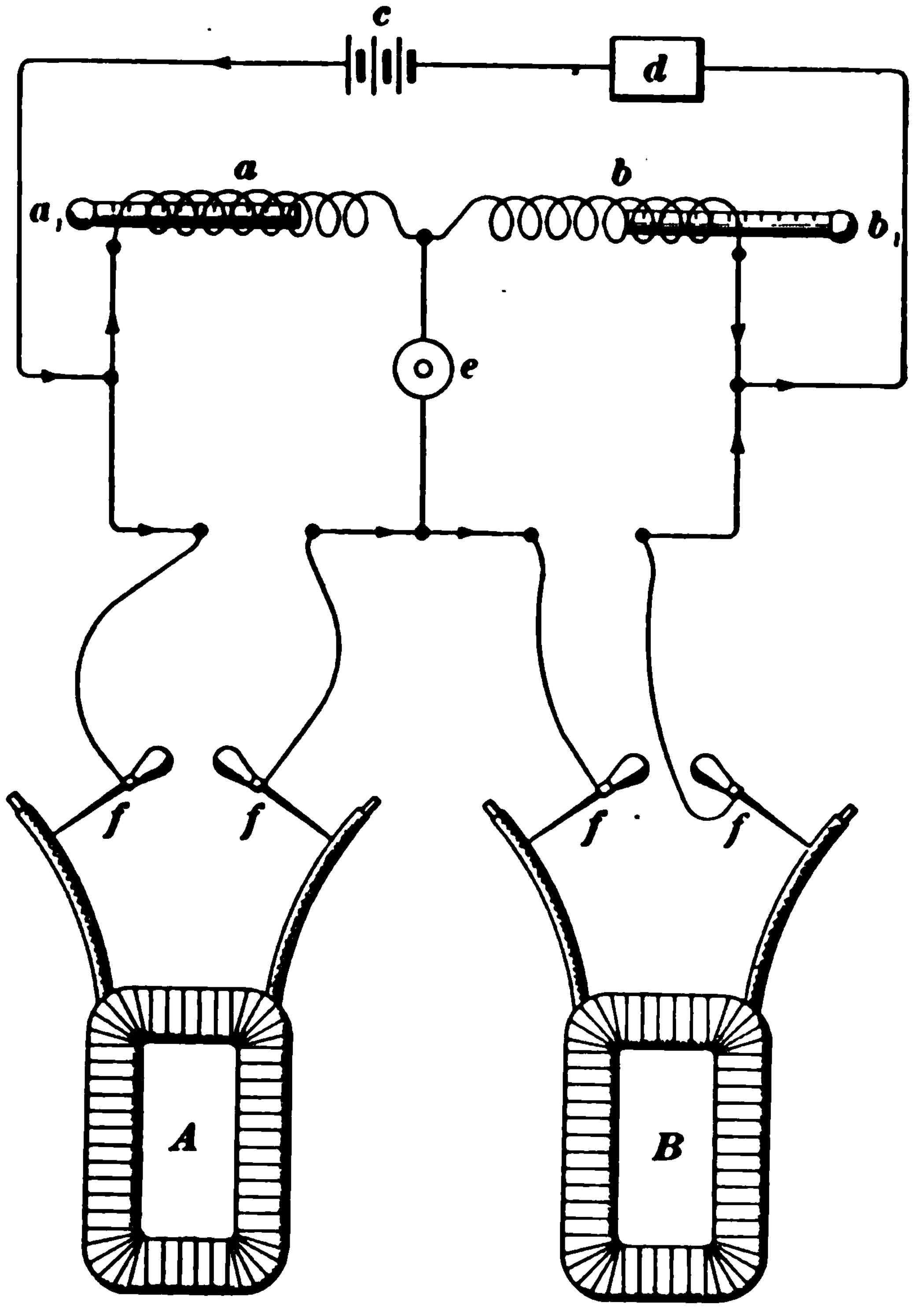



FIG. 21

alike in every particular. The minimum sound will then be obtained when cores $a_1$ and $b_1$ are adjusted so that the induced E. M. F.'s in $a$, $b$, $A$, $B$ are equal, and the position of the cores can be noted by the graduations marked on them. If, however, coil $B$ is defective because of a number of short-circuited turns, its inductance will be less than that

of *A*, and core *b*, must be drawn out farther than *a*, in order to obtain a balance; i. e., the inductance of *b* must be made less than that of *a*. In this manner the condition of a coil, as compared with a good coil, can be quickly determined, and from a knowledge of the readings obtained with good and bad coils it can be easily determined whether a given coil should be left in service or taken out and repaired. In another form of tester working on much the same principle, the operating current is obtained by connecting the instrument to a 500-volt lamp circuit of five lamps in series, the instrument taking the place of one of the lamps. This supplies about $\frac{1}{2}$ ampere; a magnetic vibrator is used to interrupt the current.

## SPEED CONTROL

### RHEOSTATIC CONTROL

**49.** Since the speed of a series motor can be varied by inserting an adjustable resistance in series, the first method of controlling the speed of street cars was by means of a resistance used in connection with a **controller**, or pair of controllers, by means of which the amount of resistance could be varied. This is known as the *rheostatic method of control*. It can be used with one or more motors, but it is now seldom employed for regular street-railway work, because it is wasteful of power, especially at the lower speeds. It is, however, used in those cases where only one motor is to be controlled and where gradual variations in speed are desired. It is employed to some extent in connection with mine-haulage plants and hoisting apparatus; also for cars operated by a single motor.

On account of the somewhat extended use of rheostatic control in connection with haulage and hoisting apparatus, some of its more important features will be considered briefly. This will also serve as a good introduction to the widely used series-parallel method described later.

### R11 CONTROLLER

**50. General Construction.**—Fig. 22 shows a rheostatic controller designed by the General Electric Company for the control of cars, haulage locomotives, or hoisting motors; it is known as the **R11 controller** and was formerly called the KR. All General Electric type R controllers are

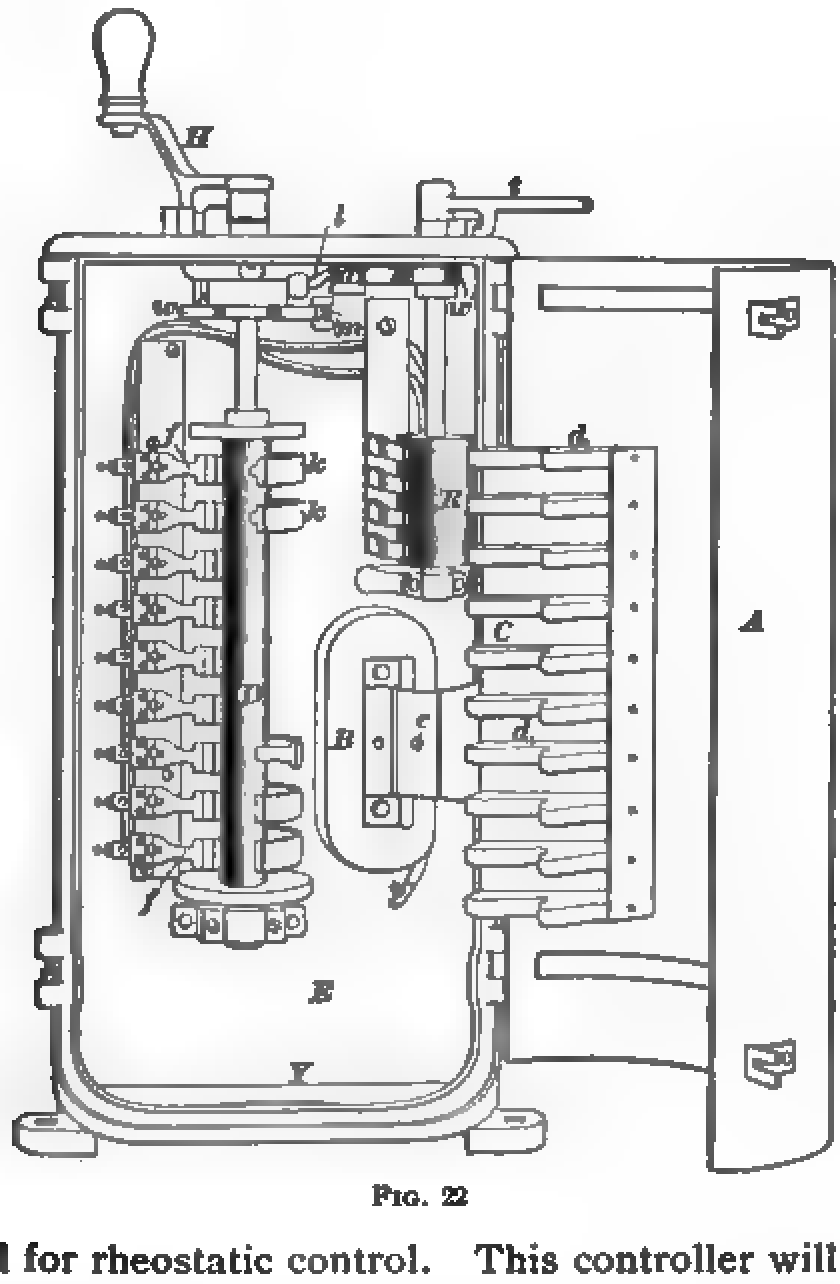


FIG. 22

intended for rheostatic control. This controller will be considered in detail because it contains many of the features found on controllers used on street cars and will serve as a good introduction to the study of them. It is designed to handle one 50-horsepower 500-volt motor or one 25-horsepower 220-volt motor; i. e., its contacts are large enough to

carry about 75 amperes. The figure shows the cover *A* thrown back so as to expose the working parts. The changes in the connections are effected by a *cylinder*, or *drum*, *D*, provided with contact segments that make connection with fingers *f*, *f* when the cylinder is rotated by means of the operating handle *H*. This controller is of the magnetic blow-out type, because a magnetic field is used to extinguish the arc that would otherwise form at the contact tips and cause blistering and burning. This method of preventing arcing has proved very effective. *B* is the coil that sets up the magnetic field necessary to blow out the arc, and is therefore called the *blow-out coil*. The iron back of the controller forms one pole piece and the hinged polar extension *C* the other; pole piece *C* is shown swung back so as to give access to the power

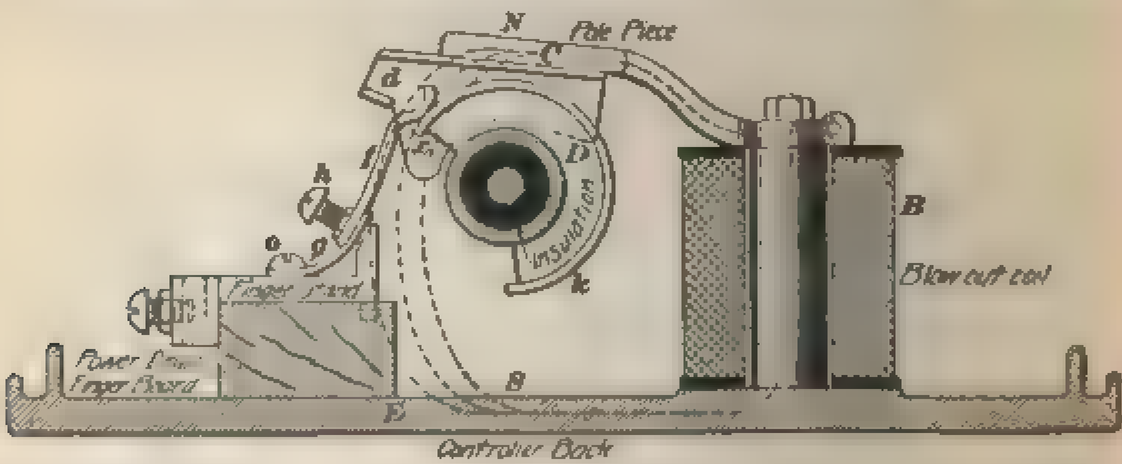



Fig. 23

cylinder *D*, but when the controller is in use, *C* is swung over and held in position by a bolt passing through hole *e*. Fig. 23 shows the relation of the pole piece *C*, cylinder *D*, and the controller back *E* when the pole piece is swung into position. The pieces *d* are *arc guards*, made of vulcabeston (vulcanized asbestos); they pass between the contact segments and prevent arcing across from segment to segment. All the current supplied to the car passes through blow-out coil *B* and sets up a magnetic field between *N* and *S*, as indicated by the curved dotted lines. When the cylinder is revolved far enough, tip *i* of segment *k* leaves finger *f* and an arc tends to form. This arc acts in the same way as a flexible wire carrying current, and is therefore forced across

the field and stretched out until it is broken. The action is practically instantaneous, so that there is little or no burning of the fingers and segments. Fingers *f* are stamped out of thick copper and are attached to a flat phosphor-bronze spring *g*, which is in turn fastened to the cast-brass finger stand by means of screws *o*, so that fingers can be replaced at any time. Screw *h* is for adjusting the amount that the finger drops when the segment passes from under it. This affects the pressure with which the fingers press on the segments, and they should be adjusted so as to drop about $\frac{1}{32}$ to $\frac{1}{16}$ inch. The cylinder segments should be rubbed frequently with a little vaseline so as to prevent wear and cutting.

**51. Star Wheel, or Index Wheel.**—The power cylinder is operated by means of handle *H*, Fig. 22, which fits on the top of the shaft. In order to compel the cylinder to take up a definite position corresponding to the various steps, it has a **star wheel, or index wheel,** *w* attached to the shaft. This engages with a spring-actuated roller *m*, which is pulled into the various notches on the star wheel and forces the cylinder into its proper position. It is this star wheel and roller that gives the movement of a controller handle its springy feeling.

**52. Reverse Cylinder.**—The reversing switch, or reverse cylinder, as it is called, is shown at *R*. This is much smaller and simpler than the power cylinder and is mounted in the upper right-hand corner of the controller. Its sole function is to reverse the armature connections in case it is desired to run the car in the opposite direction. It is not intended to turn the current on or off or effect any changes in the resistance. For this reason, the reverse cylinder is not provided with any device for suppressing arcing, and its contact fingers are somewhat lighter than those on the main cylinder.

**53. Interlocking Device.**—In order to make sure that the reverse cylinder shall not be moved while the current is on, the controller is provided with an interlocking device that makes it impossible to move the reverse cylinder unless

the power cylinder is at the off-position. The reverse cylinder shaft is provided with a star wheel $w'$ having three notches, corresponding to the off-, ahead-, and back-positions. The lever carrying the roller $r$ that engages this star wheel has a link $l$ attached to it, which runs across to the hub of the star wheel $w$. The hub of $w$ has a notch in it that comes opposite the end of $l$ when the power cylinder $D$ is at the off-position, and when the reverse handle $t$ is moved, the end of link $l$ is forced into the notch until the roller $r$ passes over the projection on the star wheel $w'$, when $l$ falls back far enough to allow $D$ to be turned. At any position of $D$ other than the off-position, there is no notch opposite the end of $l$; hence, when an attempt is made to move $t$, link $l$ butts against the hub and the reverse cylinder is locked.

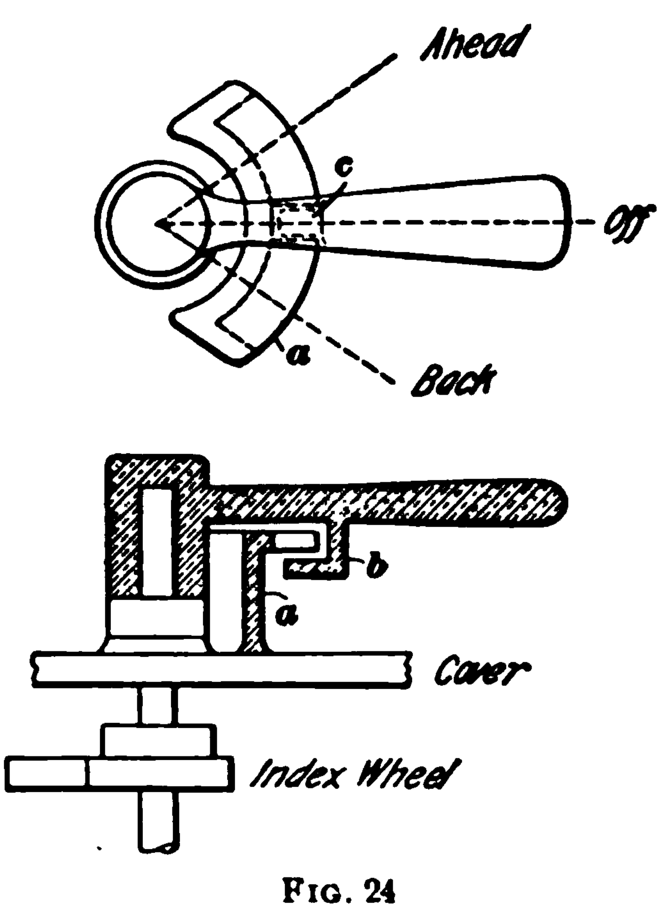


FIG. 24

When the reverse lever points ahead, the car runs forwards, and when it points back, the car runs backwards.

The reverse handle is also arranged so that it cannot be removed unless the power drum is at the off-position. An L guard $a$, Fig. 24, is cast on the controller cap and overhangs a hook $b$ cast on the handle. A notch $c$ is cut in the guard, so that the handle can be lifted off at the off-position and no other.

**54. Operation.**—This controller has six points, and a development of the cylinder with the various connections is shown in Fig. 25. This diagram shows a single motor, of which $A'$ and $F'$ are the armature and field, respectively, operated by a single controller. In this diagram and in those to follow, the cylinder segments are indicated by black bands, which represent the segments straightened or developed out flat. The finger stands on the power

cylinder and on the reverse cylinder connection boards are represented by vertical rows of black spots. The vertical dotted lines represent the various positions of the cylinder, and in studying the connections resulting from a movement of the operating handle to a given position, the developed cylinder can be considered as sliding under the contact fingers until it occupies a position indicated by the vertical

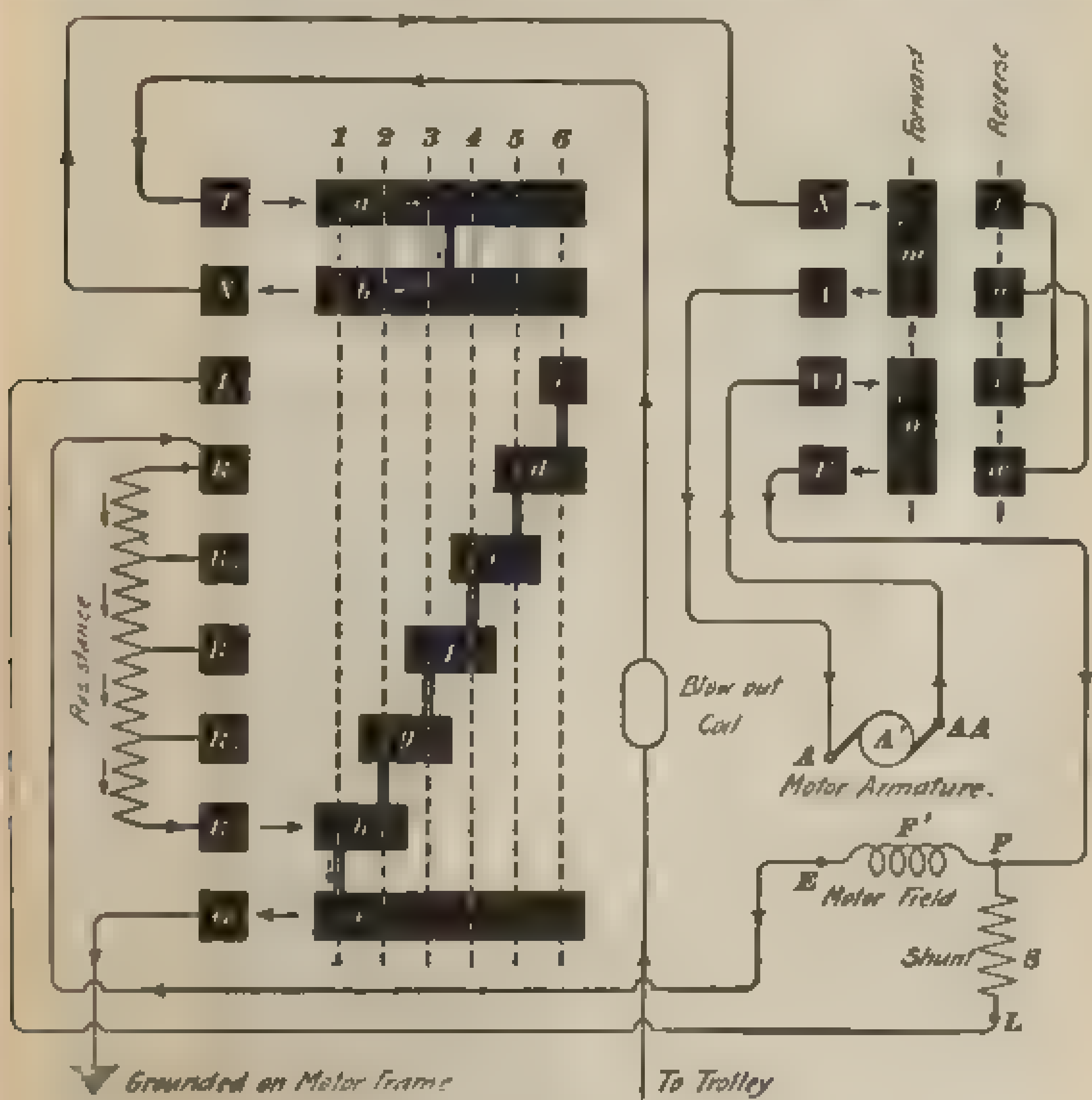



FIG. 25

dotted line that corresponds to the notch, or position, on which the handle is placed. In this case the power cylinder is in two parts. Contact segments $a$ and $b$ are connected together, but are insulated from $c, d, e, f, g, h$, and $i$, which are all connected together because they constitute a single casting. On the first notch, fingers $T, X, R_1$, and $G$ make

contact with their respective cylinder segments; all the others hang over and touch nothing.

The path of the current on the first notch, indicated by the arrows, is: Trolley blow-out coil-$T$-$a$-$b$-$X$-$X'$-$m$-$A$-$A$-armature $A'$-$A$-$A$-$A$-$A$-$n$-$F$-$F$-field $F'$-$E$-$R_1$ through the whole of the resistance-$R_5$-$h$-$i$-$G$-ground, thus completing the circuit from the trolley to the rail.

On the second notch, finger $R_4$ touches segment $g$, and when the current reaches $R_1$ it flows through three sections only of the resistance, because when it reaches $R_4$ it takes the path $R_4$-$g$-$h$-$i$-$G$. On the third notch, the section of resistance between $R_3$ and $R_4$ is cut out. On the fourth notch, that between $R_2$ and $R_3$, and on the fifth notch all the resistance is cut out, the path of the current there being: trolley-blow-out coil $T$-$a$-$b$-$X$-$X'$-$m$-$A$-$A$-$A'$-$A$-$A$-$A$-$A$-$n$-$F$-$F$-$F'$-$E$-$R_1$-$d$-$e$-$f$-$g$-$h$-$i$-$G$. The fifth notch, then gives the highest speed that can be attained by simply cutting out resistance.

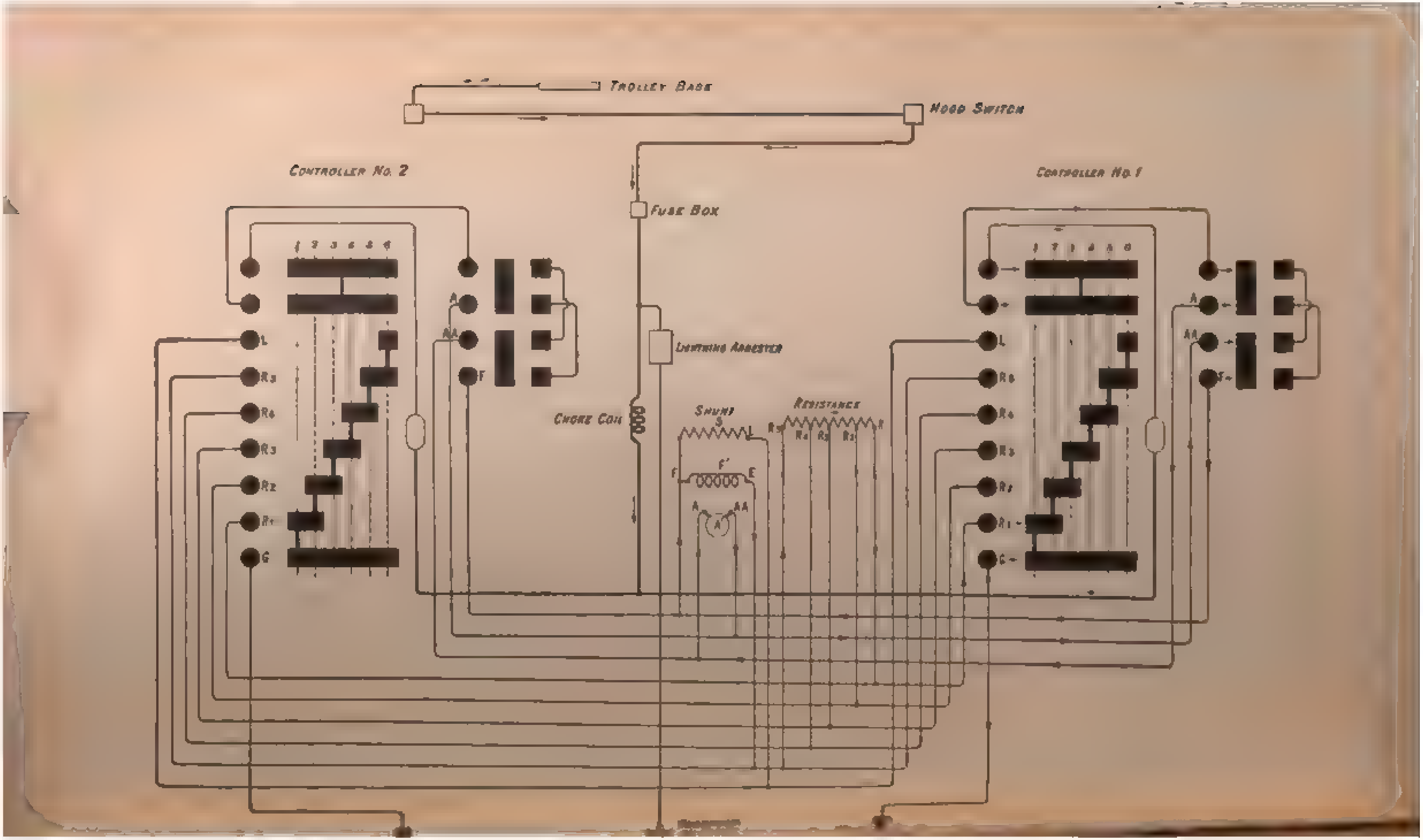
On this controller, a shunt $S$ may be used and a sixth notch is provided, so that on it the shunt will be connected across the motor field coil, thereby weakening the field and increasing the speed. One end of the shunt is attached to $F$ and the other to finger $L$. On the sixth notch, the path of the current is the same as on the fifth up to the point $F$; here the current divides, part of it taking the path $F$-$F'$-$E$-$R_1$-$d$-$e$-$f$-$g$-$h$-$i$-$G$, and the other part the path $F$-$S$-$L$-$L$-$c$-$d$-$e$-$f$-$g$-$h$-$i$-$G$, thus reducing the current in the field coil. Instead of weakening the field by means of a shunt, the same effect can be obtained by bringing out a tap from the field coil and connecting it to the wire $L$ $L$. When the controller is placed on the last position, part of the field turns are cut out, thereby weakening the field and increasing the speed. These so-called *shunt* or *loop methods* of control are now little used for street-railway work; they introduce undesirable complications and it has been found that a sufficient range of speed can be secured without them. Most recent types of controllers are therefore designed for use without loops or shunts. It is easily seen that the

controller, Fig. 25, could be used without a shunt $S$ by simply omitting the connection $L\,L$, in which case the speed on the sixth notch would be the same as on the fifth.

**55. Operation of Reverse Switch.**—If the motor is to be reversed, the reverse cylinder is thrown over, bringing contacts $t$, $u$, $v$, $w$ under fingers $X'$, $A$, $A\,A$, and $F$, respectively. When the current reaches $X'$, it takes the path $X'$–$t$–$v$–$A\,A$–$A\,A$–$A'$–$A$–$A$–$u$–$w$–$F$. In other words, it flows in at the $A\,A$ end of the armature instead of at the $A$ end as before, but it still flows in at the $F$ end of the field, thus reversing the current through the armature, but not through the field. The lettering of the various connecting posts is that used by the General Electric Company.

**56. Car With Two Rheostatic Controllers.**—In Fig. 25, only one controller is shown, but on a car or mining locomotive two controllers, one on each end, are usually necessary. Fig. 26 shows two controllers connected together for the operation of a single motor. The corresponding connecting posts of the two controllers are connected together by the wires that run the length of the car. Of course, when one controller is in use, the other is at the off-position, because the handle of the reverse cylinder cannot be removed until the power is thrown off. The arrowheads show the path of the current when controller No. *1* is on the first notch. This is practically the same as that shown in Fig. 25, except that the parts are in a little different location. The wires in this and in the following diagrams are not supposed to touch each other where they cross unless there is a round dot placed at their point of intersection. The various combinations may be represented diagrammatically, as shown in Fig. 27. The first five steps differ from each other in the amount of resistance included, and the last step is the same as the fifth, with the exception that the field $F$ is shunted.

When a rheostat is used continuously to control the speed, it must be proportioned so as to avoid overheating, and all the resistance notches may be used as running notches. With ordinary street cars, however, the resistance is not


Trolley Base
Hood Switch
Controller No. 2
Controller No. 1
Fuse Box
Lightning Arrester
Choke Coil
Shunt
Resistance

supposed to be used for speed-controlling purposes. It is only intended to give the car a smooth start and should not be used to run on. Before leaving the study of this controller, it may be well to notice that the resistance coils are here placed next to the ground, so that the current first enters the motor. In most controllers, the resistance is placed ahead of the motors; but on the whole, it makes no difference so far as the effect of the resistance itself goes; it sometimes does, however, make a difference in regard to

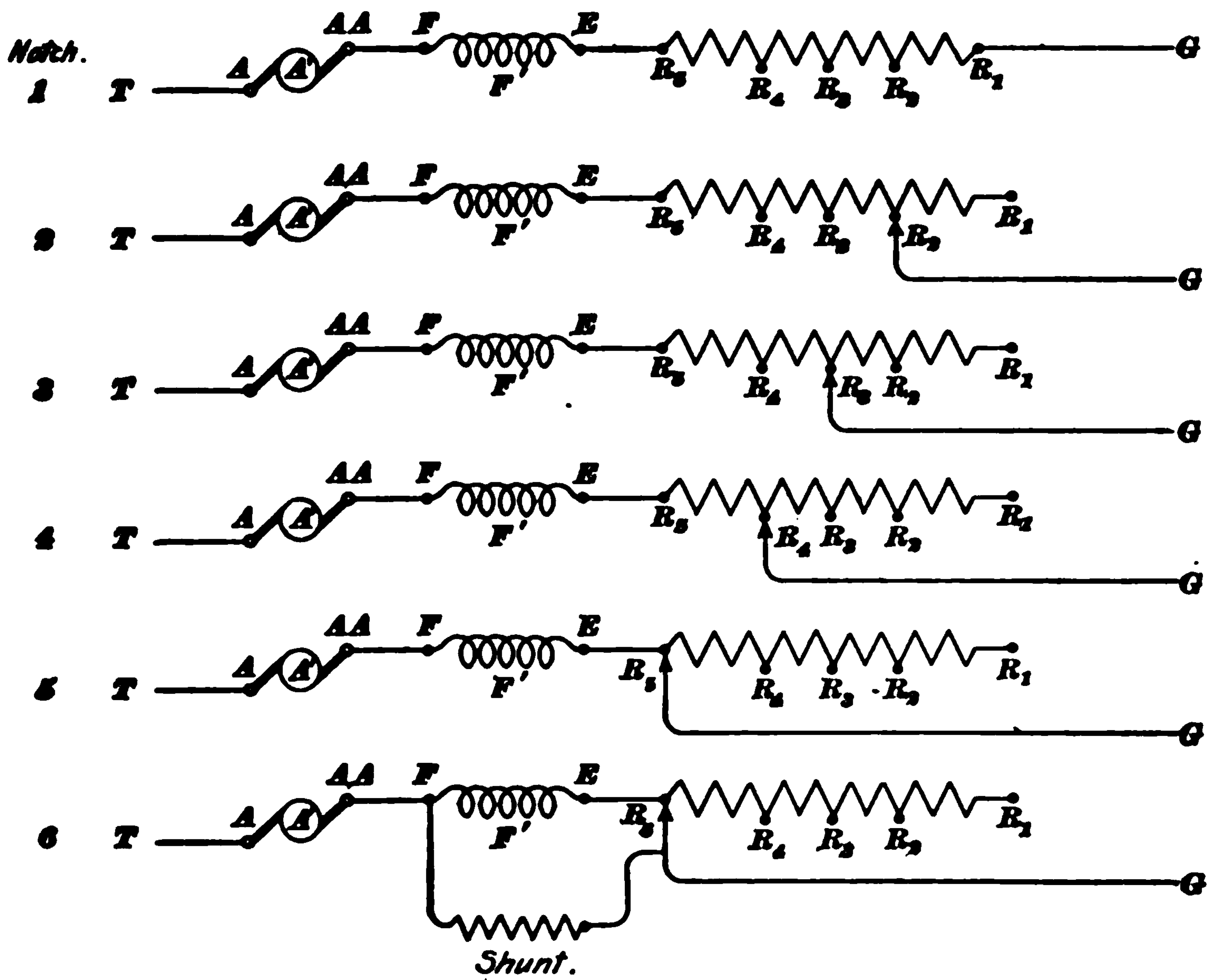



FIG. 27

the amount of trouble that arises on account of grounds occurring on the resistance. Also notice, in Fig. 26, that the post marked *AA* on controller No. *1* is connected to post *A* on controller No. *2*, and post *AA* on controller No. *2* is connected to post *A* on controller No. *1*. It is necessary to interchange the armature wires in this way so that the car will move forwards when the reverse handle on the end from which it is run points ahead.

## SERIES-PARALLEL CONTROL

**57. General Description.**—The method of speed control now almost universally used for street-railway work is known as the **series-parallel** method. It enables the voltage applied to the motors to be cut down for slow-speed running without the use of resistance, and hence is more economical on low speeds than the rheostatic method. At least two motors per car are required; hence, this method is not applicable to single-motor equipments. For slow speed, the motors are connected in series, and for high speed, they are connected in parallel; hence the name series-parallel.

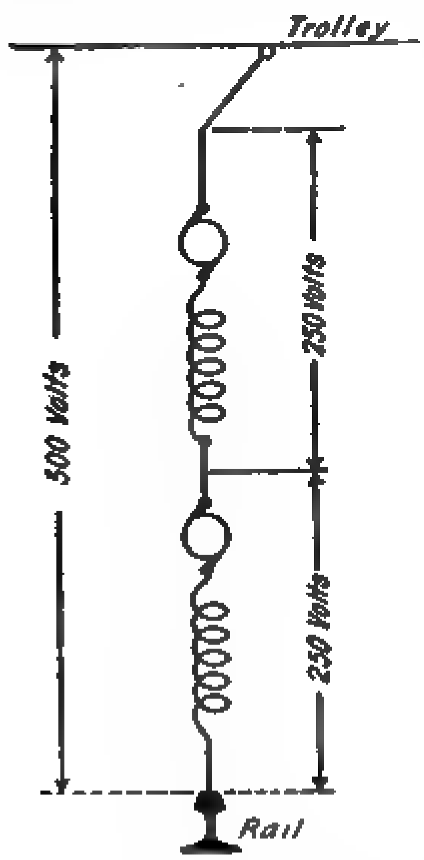



FIG. 28

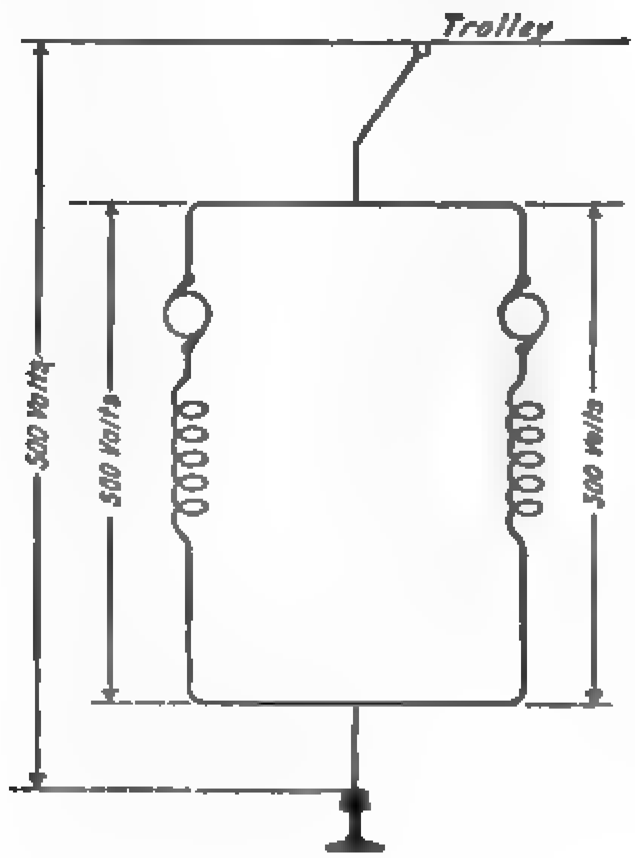



FIG. 29

Let us assume that the pressure is 500 volts; then, if the two motors on a car are connected in series, as shown in Fig. 28, the pressure across each motor will be only 250 volts. Each motor will then have to run at only about half its normal speed to generate the required counter E. M. F., and the result is that a slow speed is obtained without the use of any resistance.

When the higher speed is desired, the controller is thrown around to the "multiple notches" and effects the combinations necessary to change the motors from series to parallel. When they are in parallel, as shown in Fig. 29, a pressure of 500 volts is applied to each motor and the car runs at full speed. Of course, at starting it is necessary to include some resistance, and when changing from series to parallel, resistance is also cut in to prevent an excessive rush of current and to give a smooth acceleration to the car; but the resistance is cut out as soon as the car gets under headway and is not used on the running notches.

A great many types of series-parallel controller have been brought out, and it would be an endless task to describe all of them; the diagrams here given will, therefore, relate only to a few of the most commonly used types.

**58. Types of Series-Parallel Controller.**—The General Electric Company's series-parallel controllers are divided in two general types: type K and type L. Those designated by the letter K are intended for two or more series motors and include the feature of shunting, or short-circuiting, one of the motors when changing from series to parallel. For ordinary street cars, the K type is almost universally used, the most common controllers being the K2, K6, K10, K11, K12, and K14. Type L controllers are also intended for two or more series motors, but in changing from series to parallel, the power circuit is completely opened for an instant and then closed after the change from series to parallel has been made. Type L controllers are used mostly for large interurban cars equipped with heavy motors.

Another class of controller, known as type B, may be either rheostatic or series-parallel, but they are always provided with the necessary contacts and connections for the operation of electric brakes. Westinghouse controllers are designated in the same way as those of General Electric make and their construction is also the same.

### K2 CONTROLLER

**59. General Description.**—Type K controllers embody many of the features described in connection with the type R controller. The magnetic blow-out is arranged in the same way, and the general mechanical construction is the same, though, of course, the type K is more complicated, because it must handle all the connections for two or more motors and effect the changes necessary to throw the motors from series to parallel. It is also provided with switches, by means of which either motor may be cut out, in case it becomes disabled, allowing the car to be operated on the other motor. The K2 controller is designed for use with shunts; i. e., on the last series notch the fields of both motors are shunted and the same is also the case on the last multiple notch. The controllers may, however, be used without shunts and they are frequently run in this way.

The K2 controller is used with two motors of 40 horsepower or under and has 9 notches. There are more positions than this, but only 9 of them are marked on the controller top, and the mechanism of the controller is so fixed that the handle cannot be easily made to rest anywhere except on a marked notch. This is done so that the cylinder will not hang between notches and cause burning inside the controller. Fig. 30 shows the controller with the door opened so that the inside parts can be seen.

In Fig. 30, *1* is the operating handle that turns the controller or power cylinder *2*; *3* is the reverse handle that turns the reverse cylinder *4*; *9*, *9* are the fingers that make contact with the power cylinder and *6* is the blow-out magnet. The reverse cylinder has no blow-out coil, because it cannot be moved while the current is on. The *cut-out switches*, by means of which a disabled motor can be cut out, are shown at *7*, *7*; *8* (in the lower right-hand corner) is the *connection board*, into which run all wires from the motors and other devices, as well as the ground and trolley wires. The terminals on the connecting board also connect to the various parts of the controller, as will be shown in another diagram. The door,

or cover *12*, swings back as shown, and the bolt and wrench *10* is used for holding the pole piece in place when it is swung over; *5*, *5* are the arc guards. Both the power cylinder

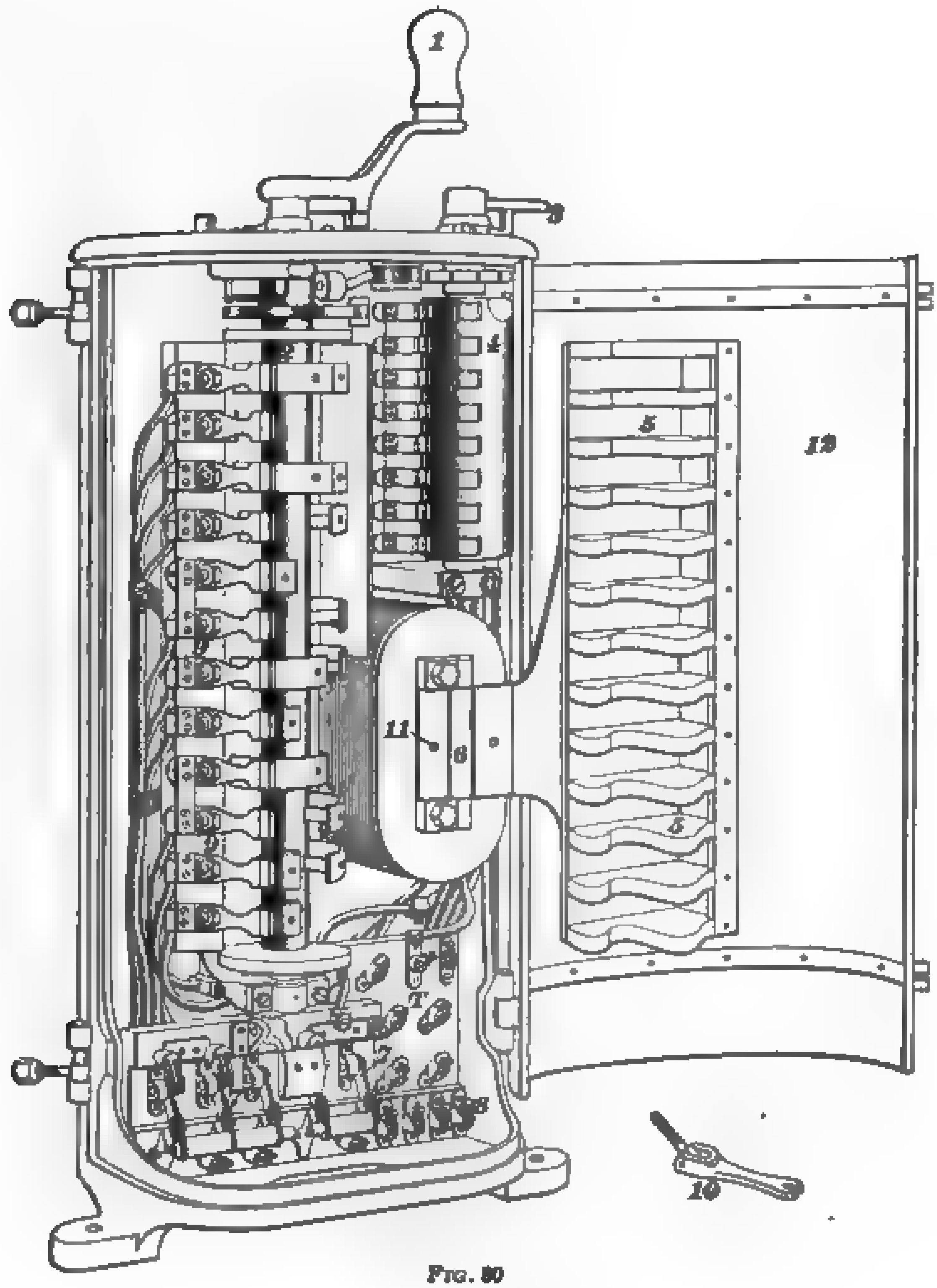



FIG. 30

and the reverse cylinder of this controller are longer than those of the rheostatic controller. The interlocking device between the two cylinders is practically the same on both, but

the connection board 8 is made necessary on account of the numerous connections and the addition of two cut-out switches 7, 7.

**60. Wiring Diagram.**—Fig. 31 shows a diagram of wiring for two K2 controllers, the lettering of the various parts corresponding to that used by the General Electric Company. The operating cylinder is made of five castings *a*, *b*, *c*, *d*, *e* insulated from each other and from the shaft. There are in all twelve positions of the cylinder, as indicated by the vertical dotted lines, but only nine of these correspond to notches in the index wheel, Nos. *6*, *7*, and *8* being transition positions that are passed over quickly while the connections are being changed from series to parallel. Of the 9 notches, only 4 are running notches, these being *4* and *5*, *8* and *9*, as indicated by the numbers above the development of the power cylinder. On each of these 4 notches, the starting resistance is not in circuit; on notch *4*, the two motors are in series with all the resistance cut out, and on *5* the connections are the same as on *4* except that the fields are shunted by shunts $L_1$ and $L_2$. If shunts were not used, the speed on notch *5* would be the same as on *4*. On notches *8* and *9*, the motors are in parallel, the fields being shunted on notch *9*, thus giving the highest possible speed.

**61.** The path of the current on the first notch is, assuming No. *1* controller to be used with the reverse switch at the forward position, as follows, beginning at the trolley post *T* on the connection board of No. *1* controller: *T*-*X*-*Y*-*1* finger–casting *a*–finger $R_1$–post $R_1$–$r_1$–whole of starting coil to $r_5$ post $R_5$–*19*–*19* on cut-out switch–*19*-*19* finger on reverse switch–segment *1*–finger $A_1$–post $A_1$–$A_1$ brush on motor No. *1*–No. *1* armature–brush $AA_1$–post $AA_1$, $AA_1$ finger on reverse switch–segment *2*–finger $F_1$–post $F_1$ field terminal $F_1$–field to $E_1$–post $E_1$ on No. *1* cut-out switch $E_1$–fingers $E_1$ $E_1$ on controller–casting *c*–finger *15*–post *15* on No. *2* cut-out switch–*15*–finger *15* on reverse switch–segment *3* finger $A_2$–post $A_2$–brush $A_2$–No. 2 armature brush $AA_2$ post $AA_2$ finger $AA_2$ on reverse switch–segment *4*–

finger $F_2$–post $F_2$–field terminal $F_2$–$E_2$–ground wire. This path is indicated by the arrowheads in Fig. 31, and it is seen that both motors are in series with all the starting resistance. As notches *2* and *3* are passed, the resistance sections are short-circuited by fingers $R_2$ and $R_3$ making contact with *a* and on the fourth notch the series running notch is used when low speed is desired. On the fifth notch, finger $L_1$ makes contact with *c* and $L_2$ and *G* with *e*, thus placing the shunts $L_1$ and $L_2$ in parallel with the fields. The sixth position is one of transition and gives the same combination as the second, part of the resistance being cut back into the circuit. On positions *7* and *8*, No. *2* motor is dropped out of circuit temporarily by fingers $E_1$ and *15* leaving casting *c*; at the same instant that a connection is made between $E_1$ and *G* (ground) by fingers $E_1$ and *G* making contact with segments *d*, thus maintaining the circuit through the No. *1* motor.

**62.** On position *9* (notch *6*), No. *2* motor is picked up in parallel with No. *1* and the last two sections of the resistance are in series as on positions *6*, *7*, and *8*. The path of the current on notch *6* is, therefore, starting from post $R_4$:

$$R_4\text{–}t\text{–}\begin{cases} 19\text{–}19\text{–}19\text{–}1\text{–}A_1\text{–}A_1\text{–}A_1\text{–}A\,A_1\text{–}A\,A_1\text{–} \\ 19\text{–}b\text{–}15\text{–}15\text{–}15\text{–}15\text{–}3\text{–}A_2\text{–}A_2\text{–}A_2\text{–} \end{cases}$$

$$\left.\begin{matrix} A\,A_1\text{–}2\text{–}F_1\text{–}F_1\text{–}F_1\text{–}E_1\text{–}E_1\text{–}E_1\text{–}E_1\text{–}d \\ A\,A_2\text{–}A\,A_2\text{–}A\,A_2\text{–}4\text{–}F_2\text{–}F_2\text{–}F_2\text{–}F_2\text{–}E_2 \end{matrix}\right\}\text{–}G$$

On notch 7, the second section of resistance is cut out, and on notch *8* all the resistance is short-circuited and the motors run with full field strength. On the last notch, the fields are shunted. Fig. 32 is a diagram of the controller top showing how the notches are indicated. Each of the raised ribs *1*, *2*, *3*, etc. corresponds to a notch, and the running notches *4*, *5*, *8*, and *9* are indicated by ribs longer than *1*, *2*, *3*, *6*, and *7*, which represent the resistance notches. Both the operating handle *H* and the reverse handle *K* are shown at the off-position. The connections at the controllers must be made so that the car will run forwards when *K* is thrown to the ahead-position. It will be noted in Fig. 31 that the armature wires are interchanged in the two controllers; for

example, the wire connecting to post $AA_1$ in No. *1* controller connects to post $A_1$ in No. *2* controller. If this were not done, the movement of the car would agree with the direction in which the reverse handle pointed when operated from one controller but would not agree when operated from the other. Also, since the motors are mounted back to back on the truck, they must run in opposite directions when viewed, say, from the commutator end, in order that they may both propel the car in the same direction. In Fig. 31 the connections are such that the current flows through both armatures in the same direction, but the direction through No. *2* field is opposite to that through No. *1* field, and No. *2*

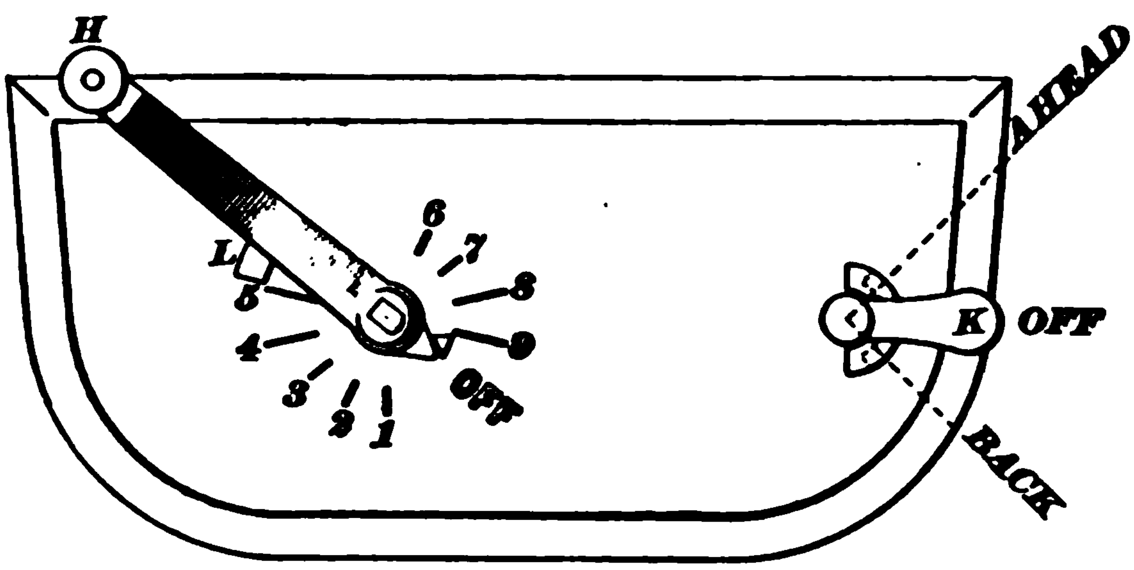



FIG. 32

motor would therefore run in a direction opposite to No. *2* when viewed from the same end. The usual method is to connect up the motors and turn on the current; if it is found that one or more of the motors are trying to drive the car in the wrong direction, they can easily be reversed by interchanging the field terminals. Fig. 33 shows diagrammatically the various combinations corresponding to the different controller positions; *S*, *S* represent the shunts across the fields and positions *4*, *5* and *11*, *12* are the only ones that should be used for steady running. The others are provided to prevent a rush of current at starting and when changing from series to parallel; also, to give a smooth acceleration.

**63. Motor Cut-Out Switches.**—In the lower part of the K2 controller, just below the power cylinder, the two motor cut-out switches are located. These are seen at *7*, *7*,

Fig. 30, and are marked No. *1* and No. *2* in Fig. 31. As mentioned before, the two motor cut-out switches are used to run the car on one motor if the other motor or any part of its circuit gives out. These two switches may be thrown up or down, and when the car is in good shape and both motors in use, both switches should be down, as indicated by the

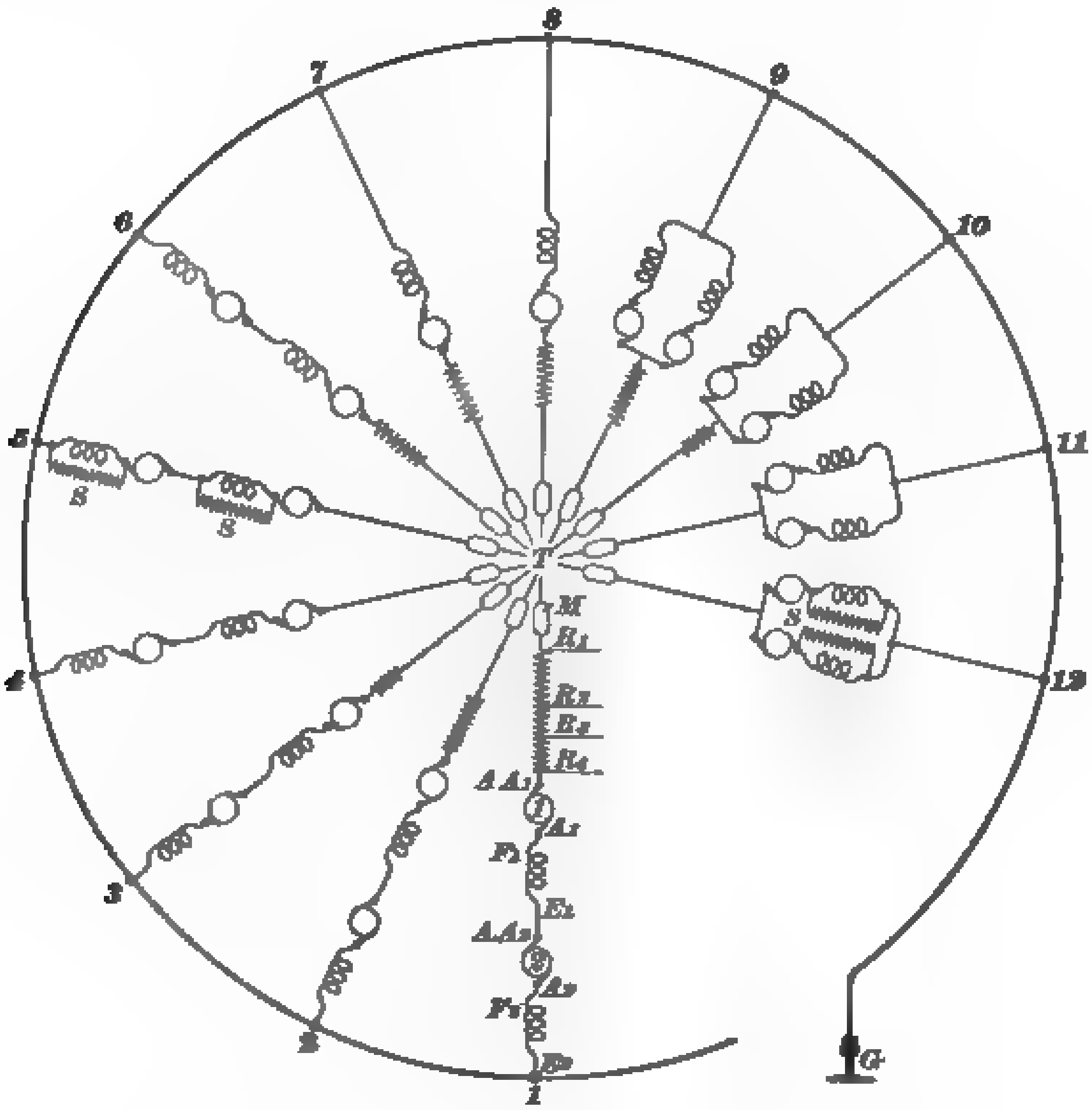



Fig. 33

connecting lines in Fig. 31. When No. *1* switch is thrown up, posts *19* and $E_1$ are connected together by casting *S*. Assuming that the controller is on the first notch, the path of the current beginning at point *1* is: *1–19–S–*$E_1$–$E_1$–$E_1$–*c–15–15–15–15–15–3–*$A_2$–$A_2$, etc. No. *1* motor is cut out and the current flows through No. *2* motor to ground. If No. *2* switch is thrown up, No. *1* being down, the current on

reaching post *15* on No. *2* switch goes directly to ground post *G* and No. *2* motor is cut out. When either of these switches is used, it operates an interlocking device that interferes with a collar on the power-cylinder shaft and prevents the cylinder from being moved beyond the last series position. It is obvious that if one motor is disabled it cannot be connected in parallel with a good motor, hence the necessity of the interlocking device to prevent the use of the parallel notches on type K controllers.

---

### K10 AND K11 CONTROLLERS

**64.** The **K10 controller** is designed for the same class of work as the K2 and has largely superseded the latter. It is the standard controller for two-motor equipments where the motors are not over 40 horsepower. In general appearance, it resembles the K2 very closely but it has eleven contact fingers for the main cylinder against twelve on the K2. The K10 controller is designed for use without field shunts, thus eliminating the two shunt contact fingers. It has, however, an additional resistance finger and there are four sections in the starting resistance; the acceleration is therefore more gradual than with the K2 controller. The **K11 controller** is practically the same as the K10, but has heavier contacts so as to carry the current for two 60-horsepower motors. The diagram, Fig. 34, may therefore be taken as applying to both controllers, the arrowheads representing the path of the current on the first notch. Fig. 35 shows the combinations effected on the various notches. On account of the omission of the shunts, there are only two running notches, one (corresponding to position *5*) where the motors are in series with all resistance cut out and the other (position *12*) where they are in parallel with all resistance cut out.

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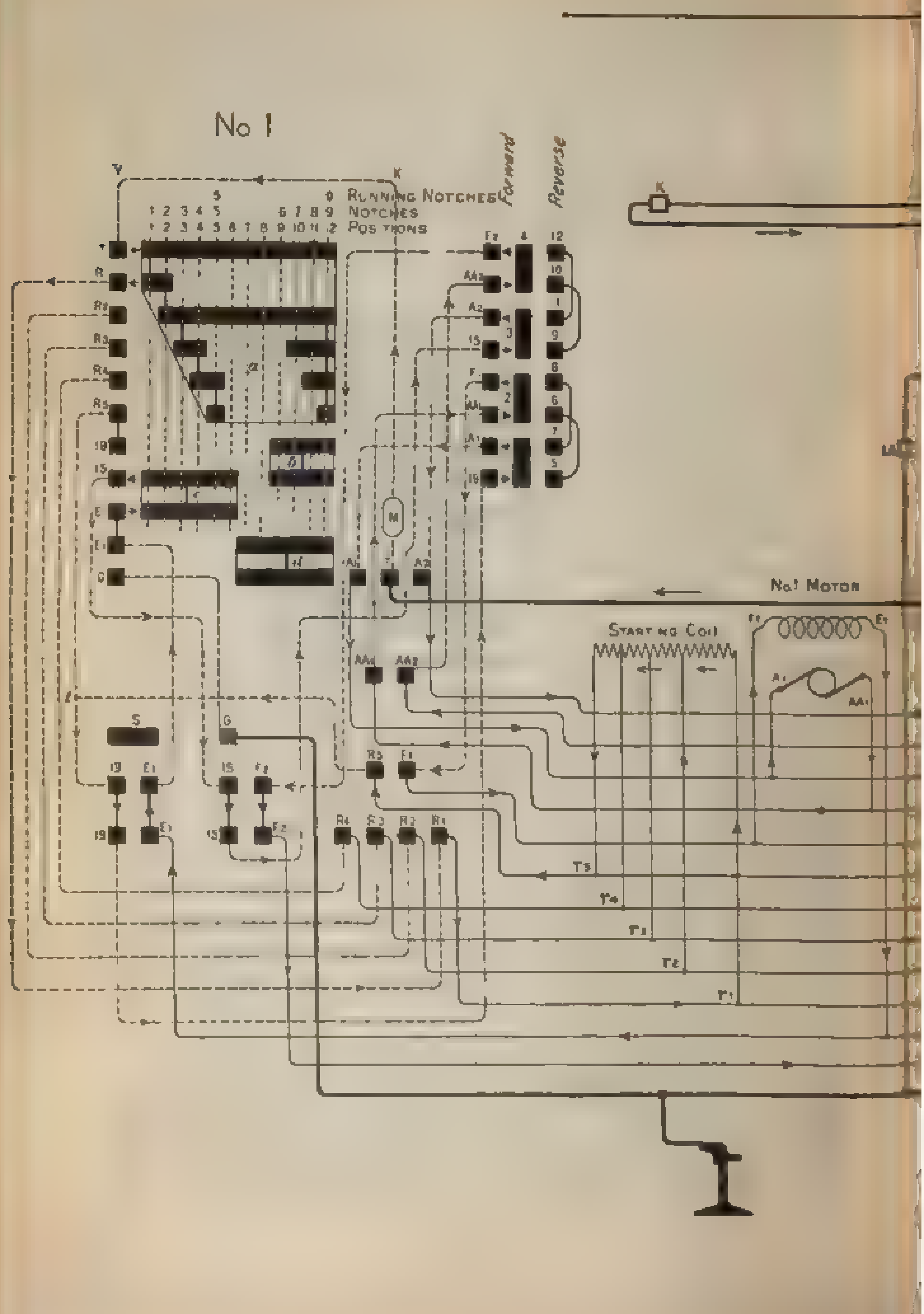
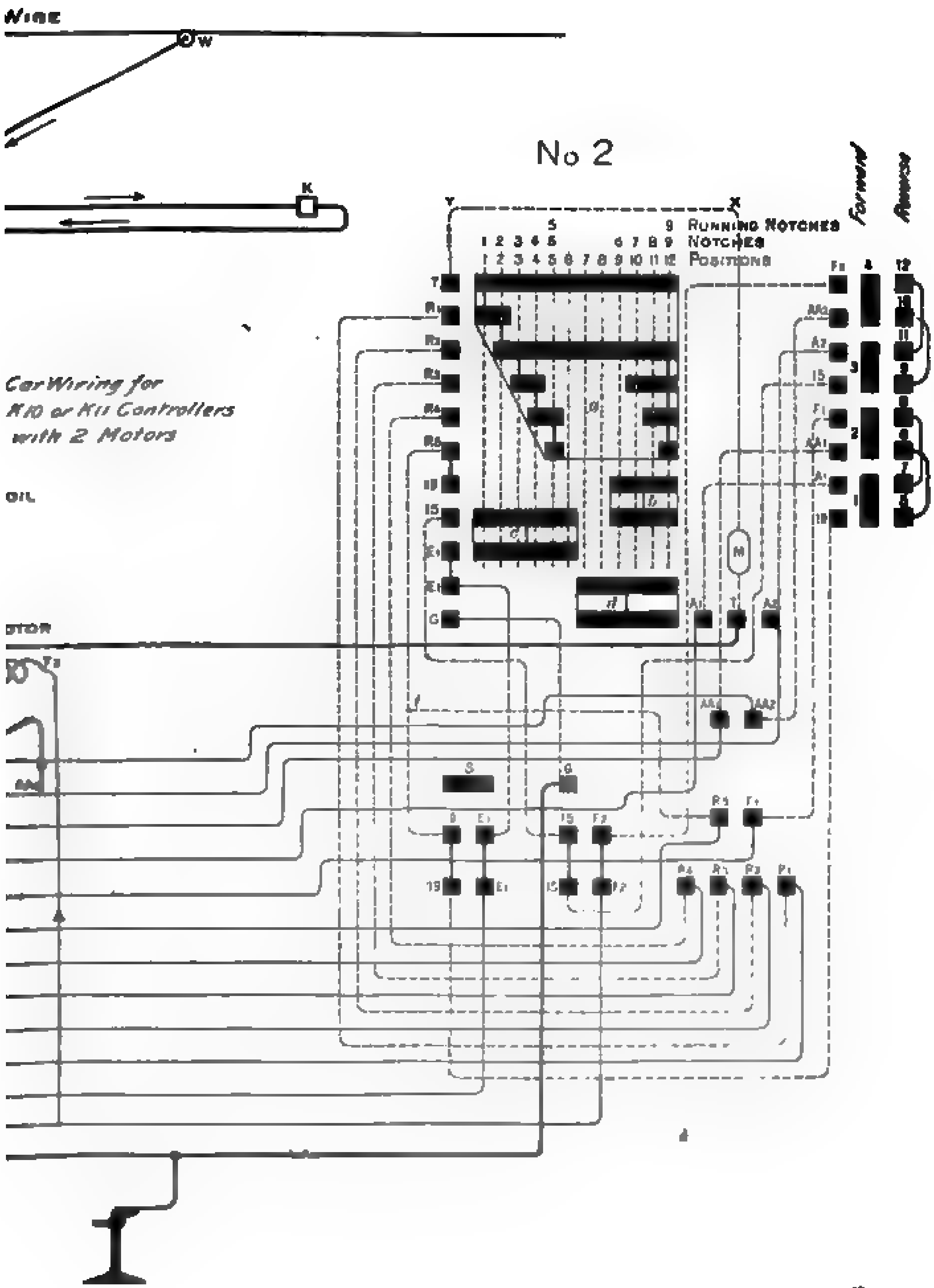
### K12 CONTROLLER

**65.** The **K12 controller** is similar to the K11, but is arranged for the control of four 30-horsepower motors. Fig. 36 shows the general layout of the wiring for a car equipped with four motors and K12 controllers. The



No 1
RUNNING NOTCHES
NOTCHES
POSITIONS
Forward
Reverse
No 1 MOTOR
STARTING COIL


No 2
Car Wiring for
K10 or K11 Controllers
with 2 Motors
Wire
Running Notches
Notches
Positions
Forward
Reverse

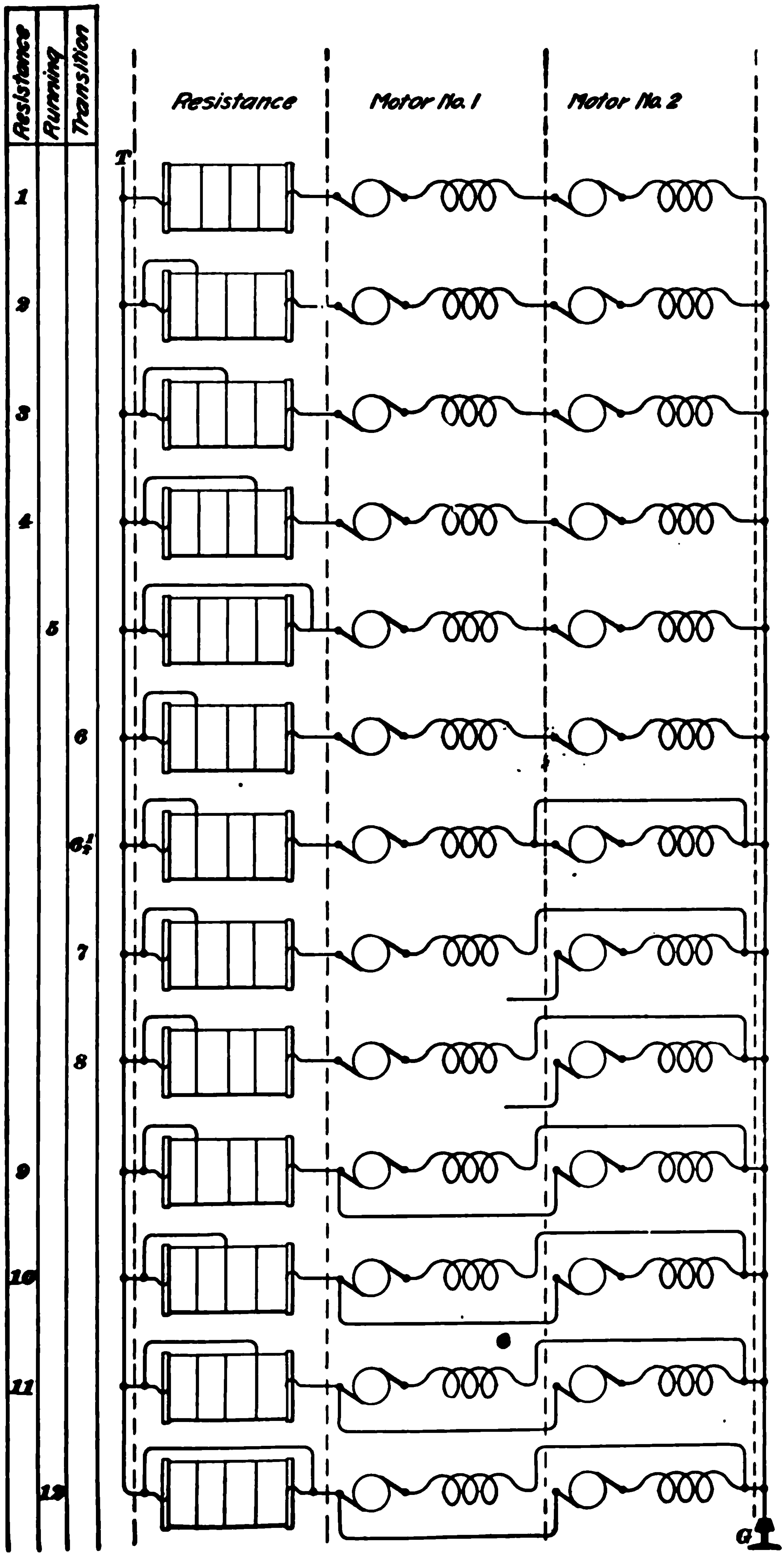

Resistance
Running
Transition
Resistance
Motor No. 1
Motor No. 2
T
1
2
3
4
5
6
$6\frac{1}{2}$
7
8
9
10
11
12
G

Fig. 35

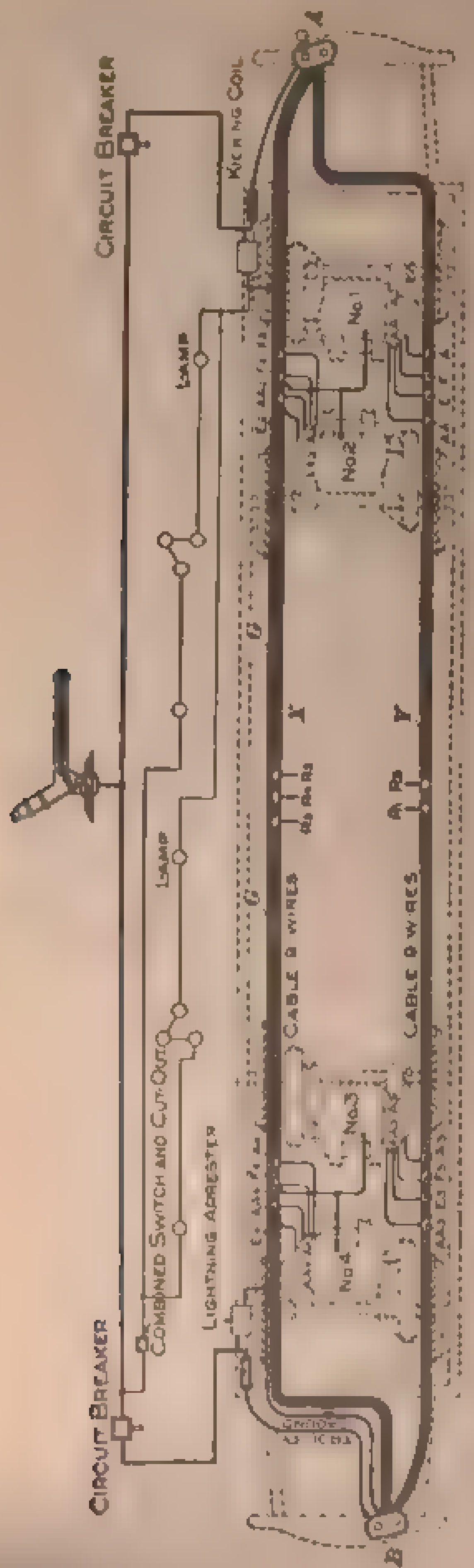



Fig. 36

motors, *1*, *2*, *3*, and *4* are mounted back to back two on each truck. The resistance coils are mounted under the middle of the car and are connected to the taps $R_1$, $R_2$, $R_3$, $R_4$, $R_5$. The two controllers *A* and *B*, the resistance coils, and the motors are connected together by wires run in the cables *X* and *Y*, or in conduit. *G G* is the ground wire, which is run separately and connected to the frames of all four motors, as shown in the figure. One end of the fields of motors No. *2* and No. *4* is also tapped to the ground wire.

The usual method for controlling a four-motor equipment is to connect the motors in pairs in parallel and then to treat the two pairs as if they were single motors, operating them by the series-parallel method, as with a regular two motor equipment. This will be understood by referring to Fig. 37, which shows the various combinations effected by the K12 controller.

By referring to Fig. 35, it will be seen that the

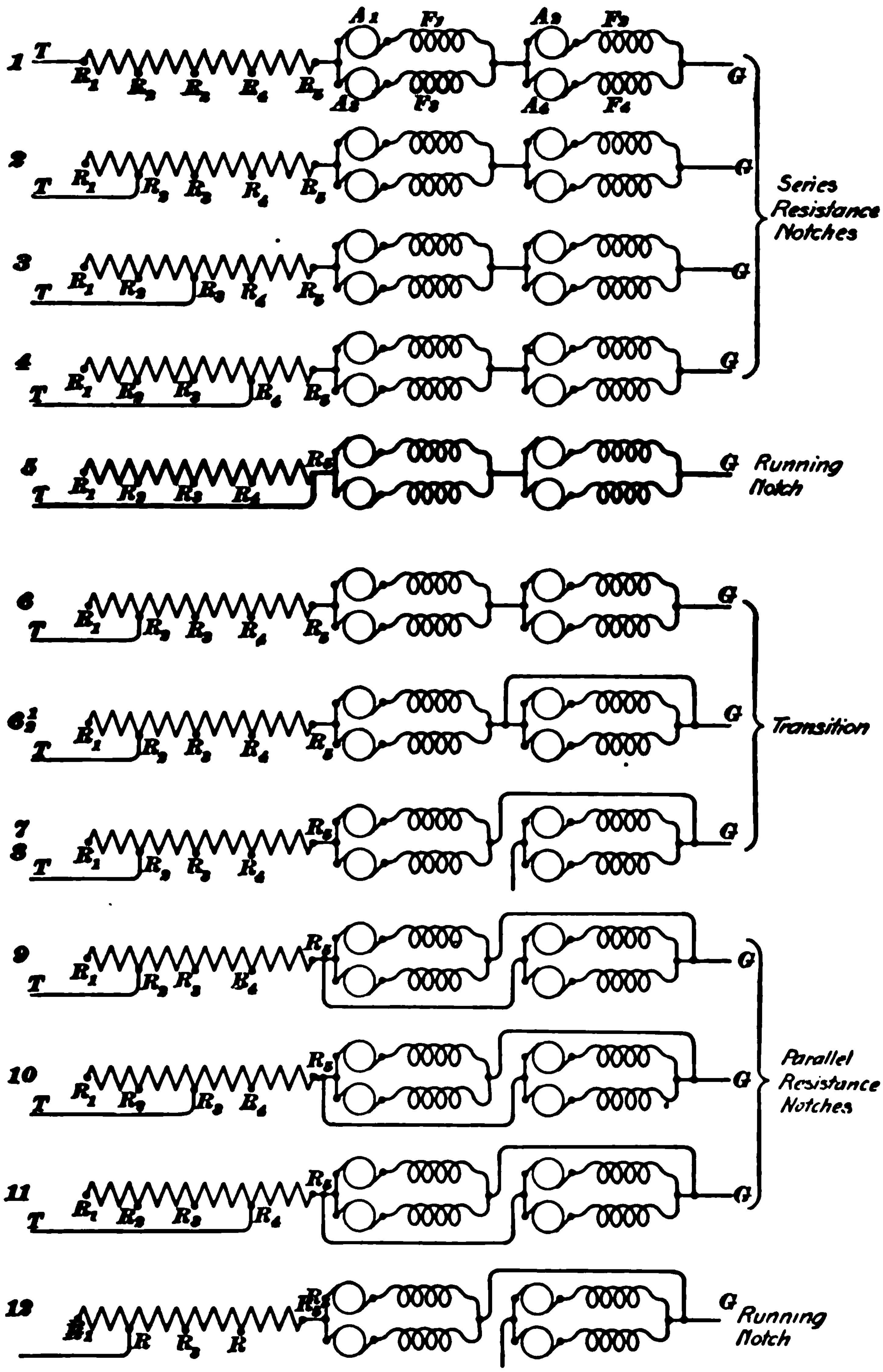

Series
Resistance
Notches
Running
Notch
Transition
Parallel
Resistance
Notches
Running
Notch

FIG. 37

combinations in Fig. 37 are practically the same as for the K11 controller, except that there are four motors in two pairs instead of the two single motors; No. *1* motor is connected in parallel with No. *3*, and No. *2* with No. *4*, so that a motor on one truck is connected in parallel with a motor on the other (see Fig. 36). There are two running notches, *5* and *9*, corresponding to controller positions *5* and *12*.

**66.** Fig. 38 is a car-wiring diagram for K12 controllers with four motors. The power cylinder is practically the same as that of the K11 but the reverse switch is different, being provided with a double row of contact fingers so that the current in all four armatures can be reversed when the car is to be run in the reverse direction. When the car runs ahead, reverse-switch fingers *b* are in contact with plates *a* and fingers *d* are in contact with *c*. When the car runs back, fingers *b* make contact with *c* and *d* with *e*, thus reversing the current in all four armatures. The leads $E_2$ and $E_4$ from the No. *2* and No. *4* motor fields are permanently connected to the ground wire. The main trolley wire connects to the blow-out coil, as shown. The path of the current on the first notch is indicated by the arrows and is as follows, starting from post $T$ at the power cylinder: $T$–$R_1$–$R_1$–$R_1$, through all resistance, –$R_5$–$R_5$–*19*–

$$\left\{\begin{array}{c} 19\text{–}A_1\text{–}A_1\text{–}A_1\text{–}A\,A_1\text{–}A\,A_1\text{–}A\,A_1\text{–}F_1\text{–}F_1\text{–}F_1\text{–}E_1\text{–}E_1\text{–}E_1\text{–}3 \\ 19'\text{–}A_3\text{–}A_3\text{–}AA_3\text{–}AA_3\text{–}F_3\text{–}F_3\text{–}E_3\text{–}E_3\text{–}E_3\text{–}3 \end{array}\right\}\text{–}$$

$$15\text{–}15\text{–}\left\{\begin{array}{c} 15\text{–}A_2\text{–}A_2\text{–}A_2\text{–}A\,A_2\text{–}A\,A_2\text{–}A\,A_2\text{–}F_2\text{–}F_2\text{–}F_2\text{–}E_2 \\ 15\text{–}15'\text{–}A_4\text{–}A_4\text{–}A\,A_4\text{–}A\,A_4\text{–}F_4\text{–}F_4\text{–}E_4 \end{array}\right\}\text{–}G$$

The other combinations are indicated by Fig. 37, and may be easily traced out on the diagram. When the cut-out switches are operated, the motors are cut out in pairs; for example, if something goes wrong with the No. *1* motor and the cut-out switch is thrown up, motors No. *1* and No. *3* are cut out.

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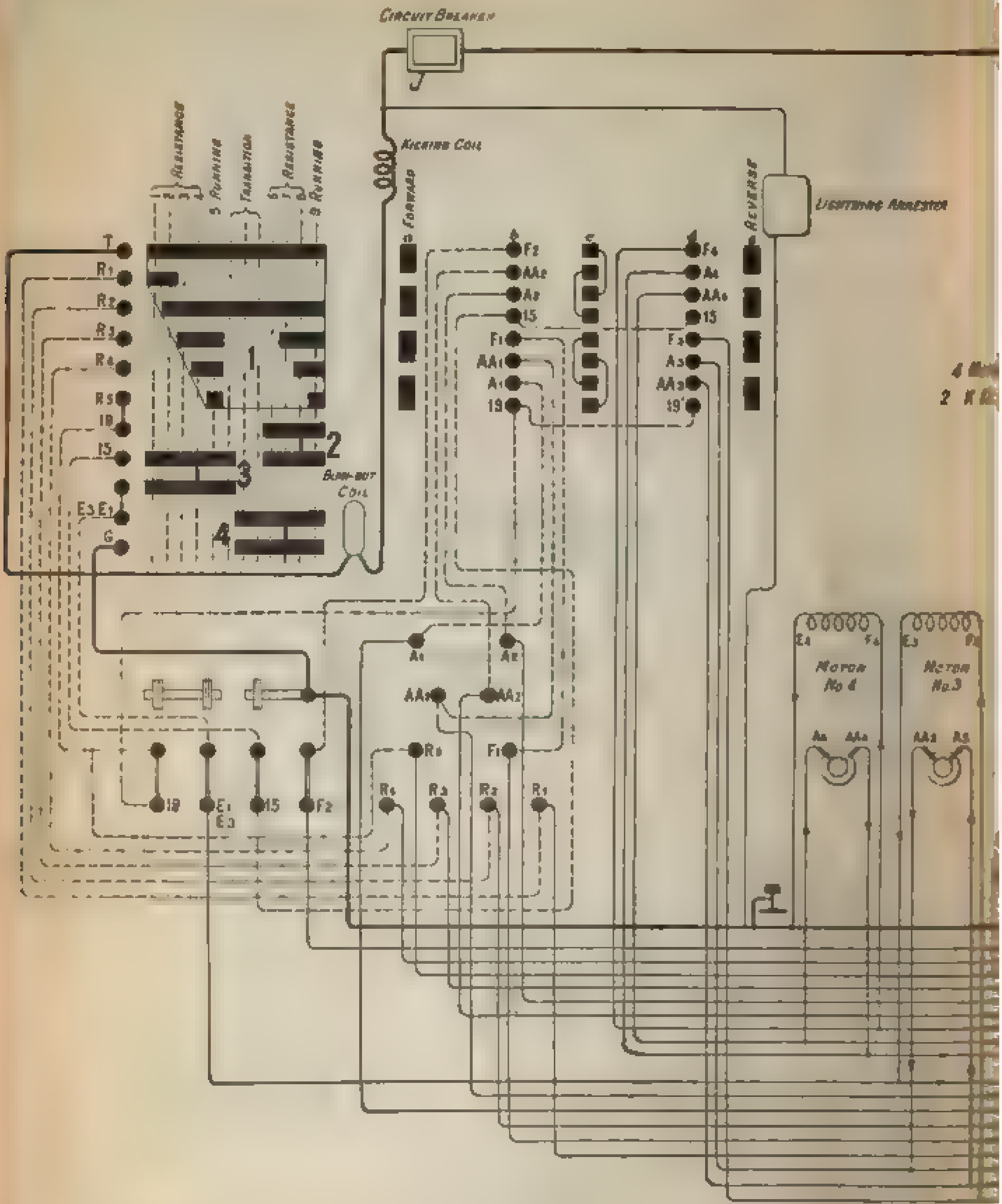
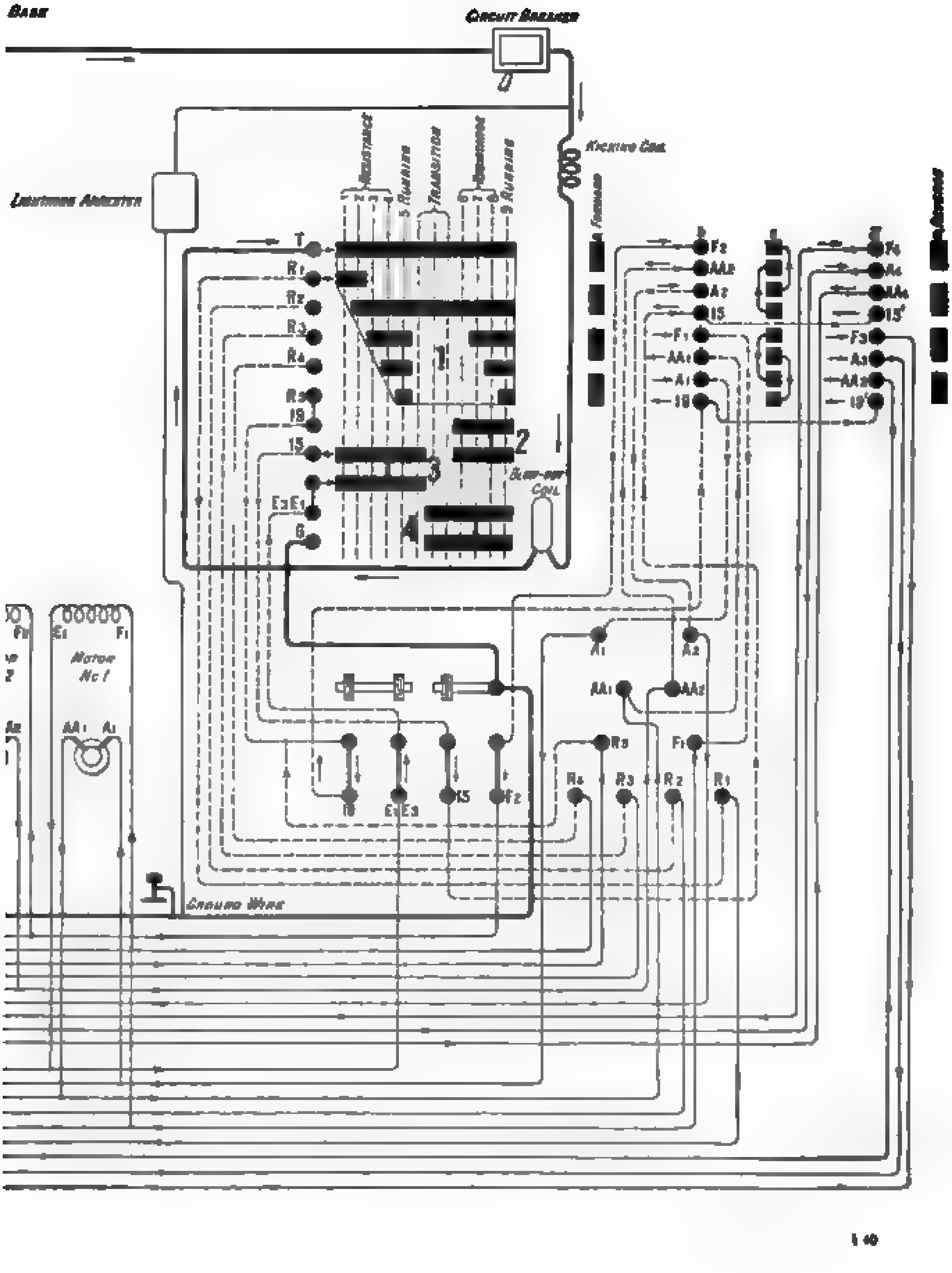
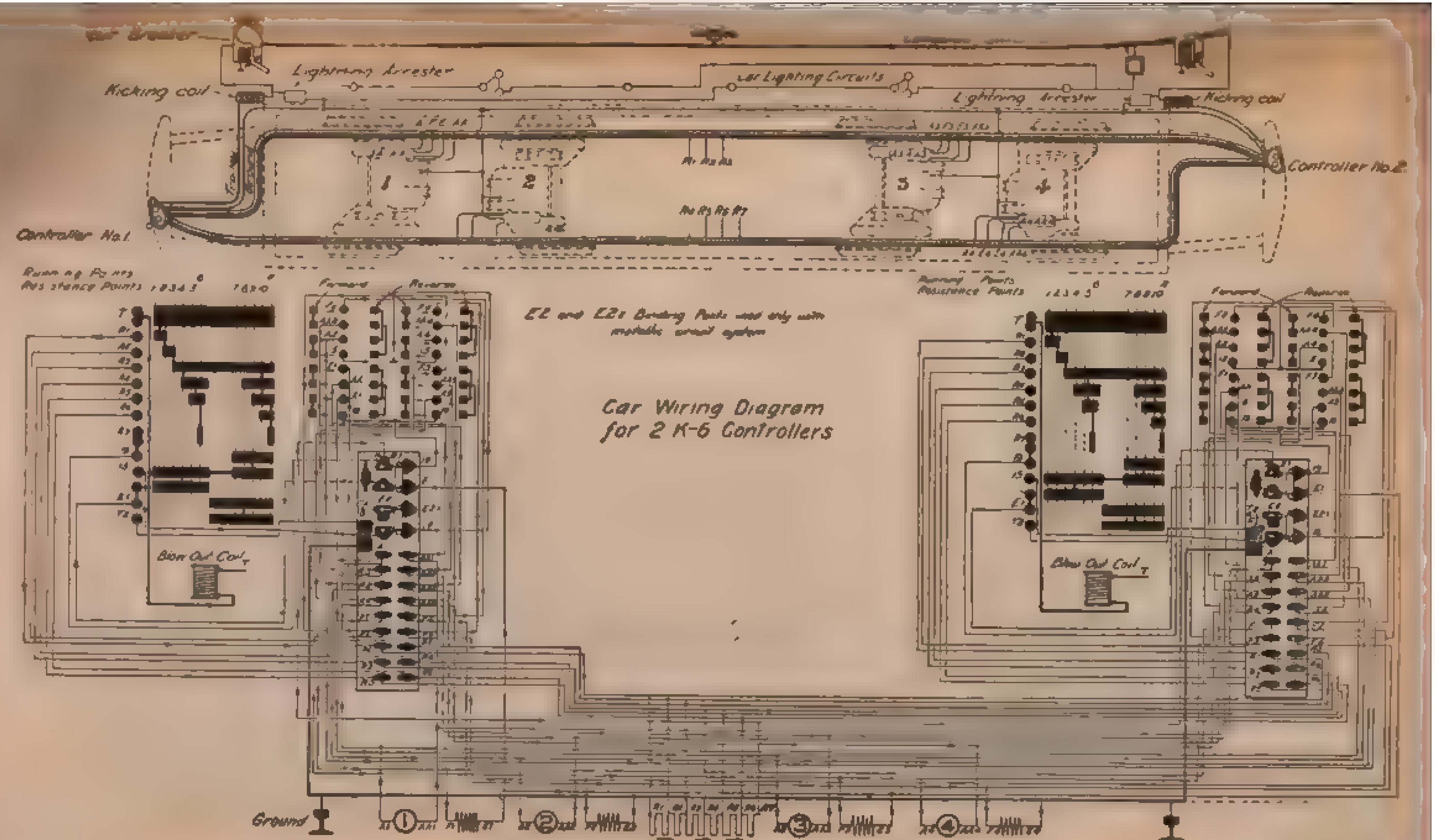
### K6 CONTROLLER

**67.** The **K6 controller** is of larger capacity than the K12 and is intended for the control of four 40-horsepower motors or two 80-horsepower. In its general construction it is



Circuit Breaker
Kicking Coil
Lightning Arrester
Resistance
Running
Transition
Forward
Reverse
Burn-out Coil
Motor No 4
Motor No.3


Circuit Breaker
Kicking Coil
Lightning Arrester
T
R1
R2
R3
R4
R5
19
15
E2 E1
G
1
2
3
4
Blow-out Coil
F2
AA2
A2
15
F1
AA1
A1
19
F4
A4
AA4
15'
F3
A3
AA3
19'
Motor No 1
E1
F1
AA1
A1
A2
AA2
R5
R4
R3
R2
R1
E2 E1
Ground Wire



Car Breaker
Lightning Arrester
Car Lighting Circuits
Lightning Arrester
Kicking coil
Kicking coil
Controller No. 2
Controller No. 1
Running Points
Resistance Points
Forward
Reverse
Running Points
Resistance Points
Forward
Reverse
E2 and E2r Binding Posts used only with metallic circuit system
Car Wiring Diagram
for 2 K-6 Controllers
Blow Out Coil
Blow Out Coil
Ground


FIG. 80

similar to the K12 but the main cylinder and contact fingers are heavier. The pole piece carrying the arc guards is also arranged differently and the blow-out coil is in the bottom of the controller, the connection board being arranged vertically at the right-hand side. The reverse cylinder has four rows of segments mounted on it and there are two rows of contact fingers. Fig. 39 is a diagram of the car wiring showing the path of the current on the first notch. There are 11 notches, 6 of which are for the series connections and 5 for the parallel. When the reverse switch is on the forward position, the two rows of segments indicated by the arrows engage with the contact fingers, and when thrown to the other position the other sets of segments engage with the contact fingers, thus reversing the current in all four armatures. Motors No. *1* and No. *3*, No. *2* and No. *4* are connected permanently in parallel, the method of control being practically the same as was described for the K12 controller.

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### K14 CONTROLLER

**68.** The **K14 controller** is designed for the control of four 60-horsepower motors; it has seven series notches and six parallel, *7* and *13* being the two running notches. Since this controller has to carry quite a large current, its construction differs somewhat from the K controllers that have been described. Fig. 40 is a general view with the cover removed and the pole piece swung back. The main cylinder *a* is driven through gears *b*, *c* by the operating handle *d*, the angle turned through by the drum being greater than the angle through which the operating handle is turned from the on- to the off-position. The main cylinder rotates in a direction opposite to that on ordinary controllers; hence, the contact fingers are placed to the right of the cylinder. The reverse cylinder is at *e* and is operated by handle *f*; cylinders *e* and *a* are interlocked and handle *f* cannot be removed until both cylinders have been turned to the off-position. The trolley connection with the main cylinder is made at *g*, at the bottom of the cylinder, instead of at the top, as in the

controllers so far described. Instead of using a regular contact finger at *g*, contact is made with the cylinder by means of a split casting passing completely around a collar. This casting can be adjusted by nut *h*, so as to make a good contact without interfering with the movement of the cylinder, and it affords a better contact surface for the larger current than would be provided by a contact finger. The cut-out switches are located at *k*, *k* and are arranged in connection with an interlock to prevent the drum from being moved to the parallel position when either motor is cut out. This controller has no index wheel, but the notches are located by a hinged lever *m*, under the operating handle, that drops into notches, in an index *l* mounted on top of the controller. Lever *m* is raised so as to clear the notches, by the motorman pressing down on knob *n* on top of the operating handle. The controller has no connection board, the terminal wires being brought out of the bottom of the controller and fastened to the car wires by means of clamp terminals that are thoroughly taped over after the connections have been made.

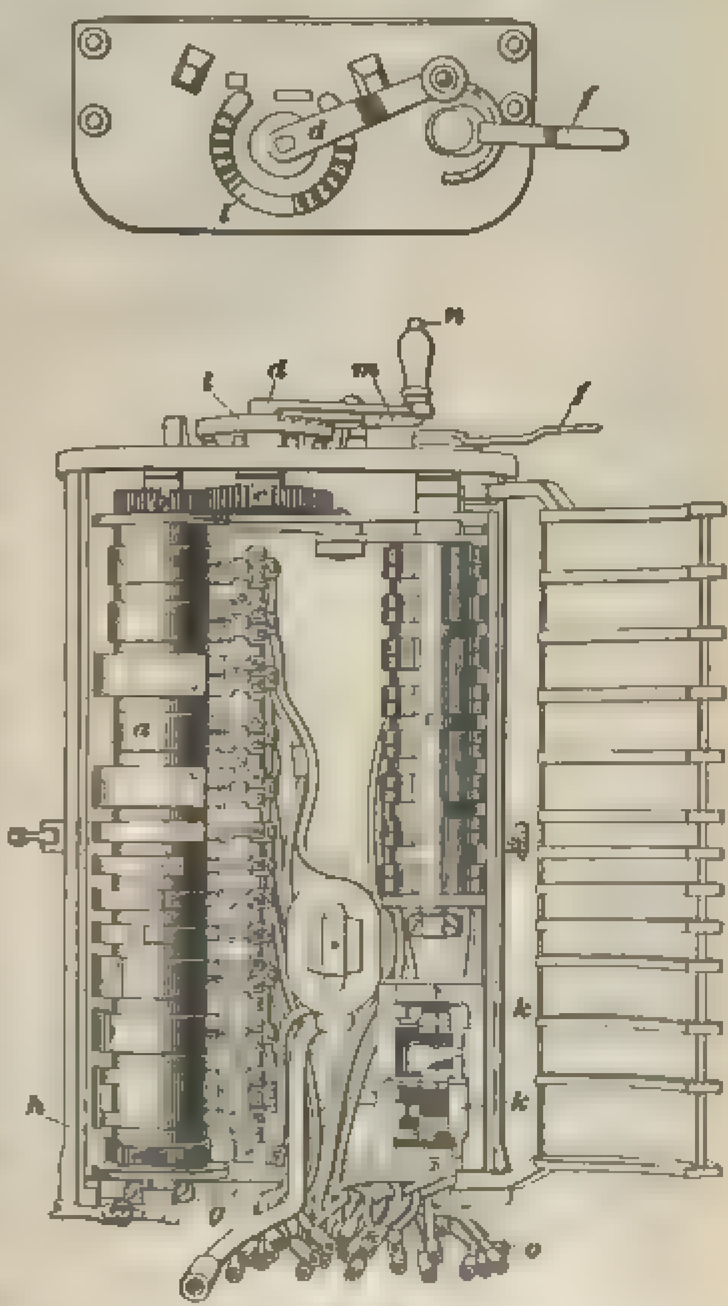
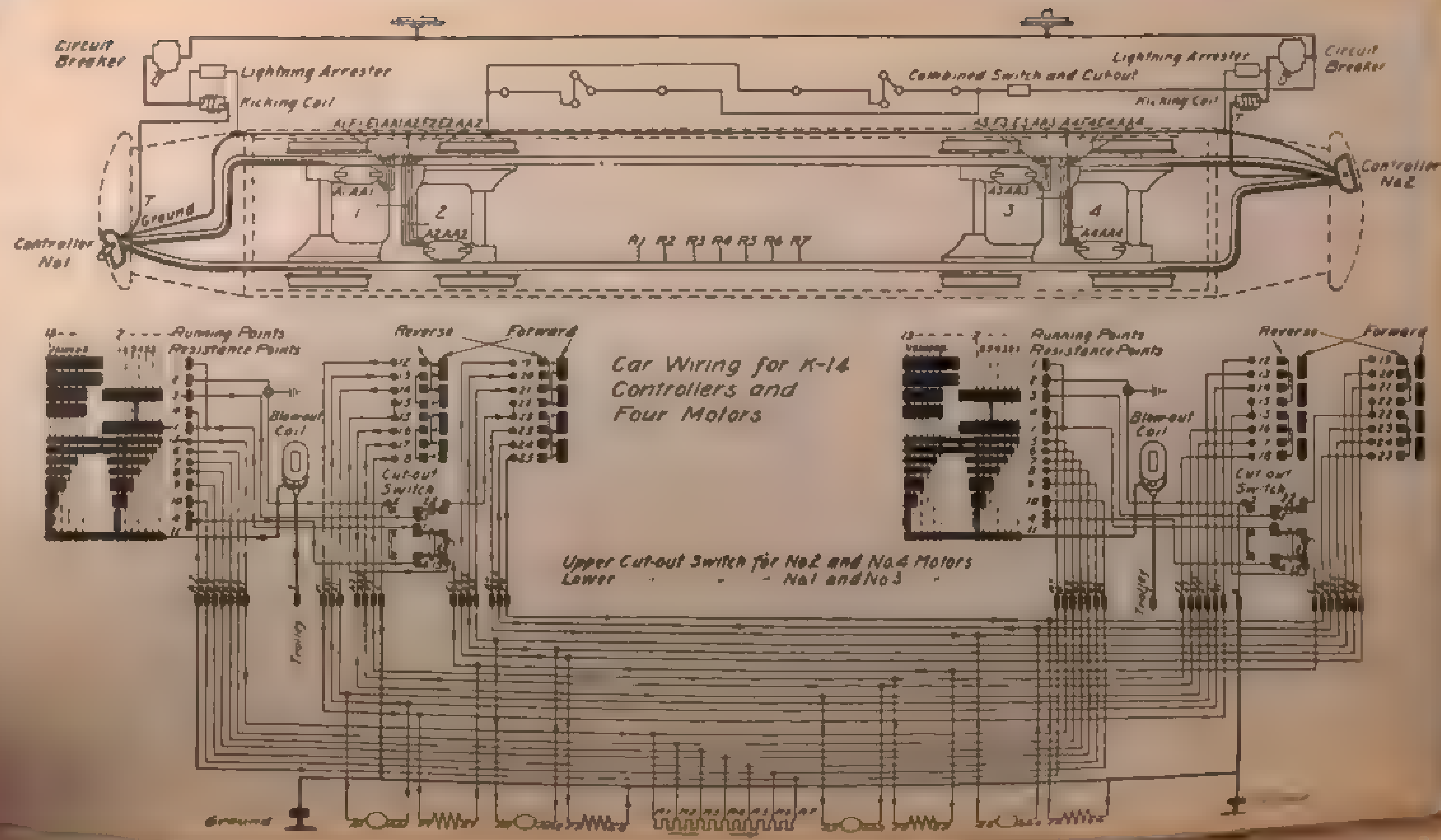


Fig 40



Car Wiring for K-14
Controllers and
Four Motors
Upper Cut-out Switch for No.2 and No.4 Motors
Lower - - - No.1 and No.3 -
Circuit Breaker
Lightning Arrester
Kicking Coil
Combined Switch and Cutout
Controller No.1
Controller No.2
Ground
Running Points
Resistance Points
Reverse
Forward
Blowout Coil
Cut-out Switch
Trolley
R1 R2 R3 R4 R5 R6 R7

Fig. 41 is a car-wiring diagram for K14 controllers with four motors, the path of the current on the first notch being indicated by the arrows. Motors *1* and *3*, and *2* and *4* are connected permanently in parallel.

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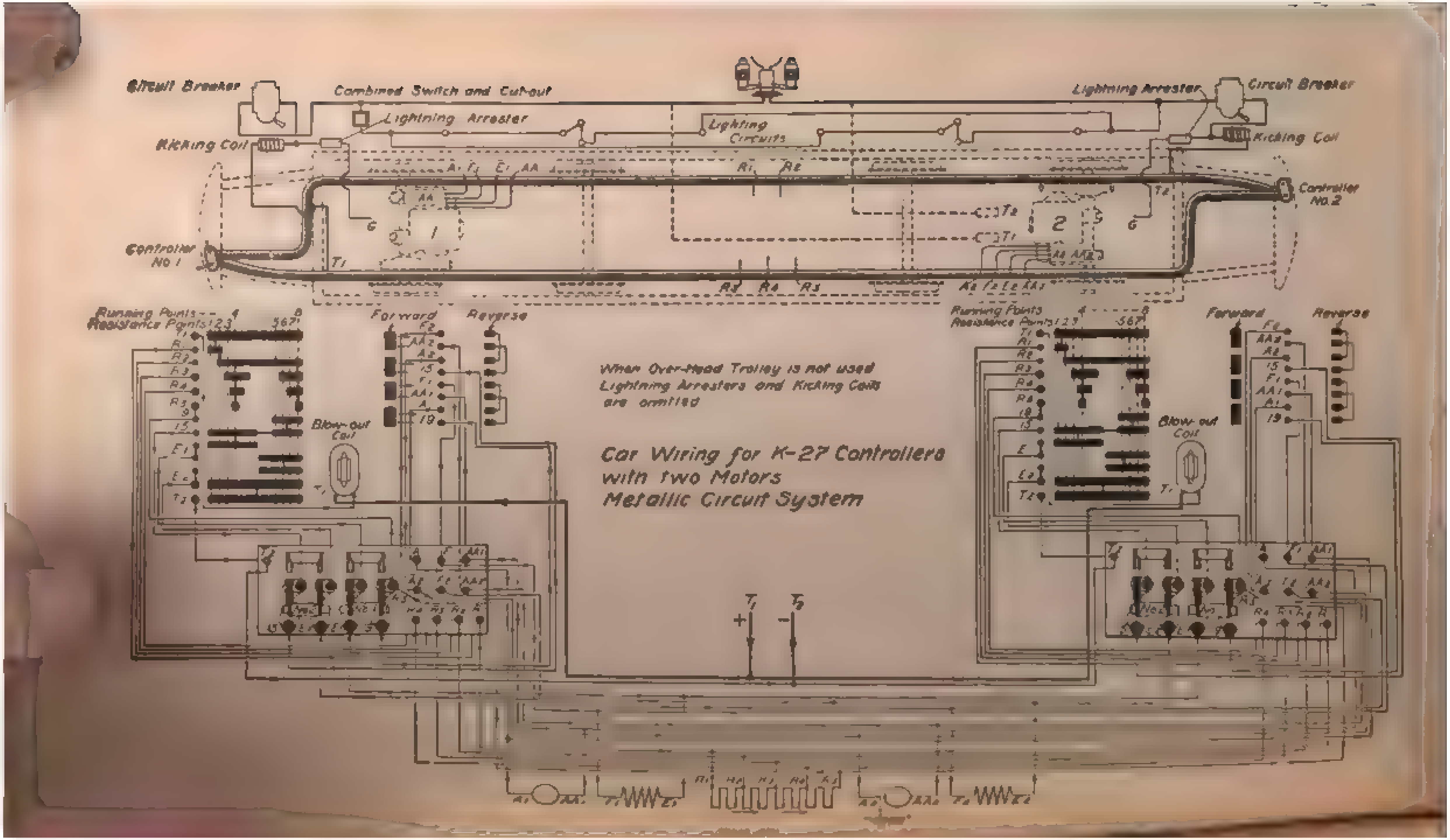
### K27 CONTROLLER

**69.** The **K27 controller,** for which Fig. 42 is a car-wiring diagram, is intended for use with two motors, not exceeding 60-horsepower, on metallic-return systems. It is used mostly on conduit systems, which are particularly liable to grounds, and on this account the controller contains a few features not found on ordinary K controllers. Any type K controller can be used for operating cars on a conduit system so long as both car and conductor rails are free from grounds; but should a car with a grounded connection run on to a section of conductor rail that is also grounded, conditions may arise where one of the motors would take current even with the controller thrown to the off-position, thus making the motorman lose control of the car and necessitating the opening of a circuit-breaker or hood switch in order to stop the car. The K27 cylinder is therefore designed so as to open both sides of the circuit when it is thrown to the off-position.

Suppose, for the present, in Fig. 42, that main cylinder fingers $E_2$ and $T_1$ are connected by a piece of wire. This will make the conditions the same as if an ordinary K10 controller were used, since with it, the end $E_2$ of the No. *2* field is connected to the negative, or ground side of the circuit, which with a metallic-return system corresponds to the $T_1$ terminal, or collecting shoe. Also suppose, in Fig. 42, that the $A_2$ brush, or a wire connected to it, becomes grounded as indicated by the dotted connection at $G'$, and assume that the car runs on to a section where the conductor rail to which $T_1$ connects is grounded. Current can then flow from the positive conductor rail through the ground and enter No. *2* motor through the ground $G'$ and flow through the path: $A_2$–$A\,A_2$–$A\,A_2$–$A\,A_2$–$F_2$–$F_2$–$F_2$–$E_2$–post $E_2$ on controller. Now we have assumed $E_2$ and $T_1$ to be connected;


Circuit Breaker
Combined Switch and Cut-out
Lightning Arrester
Kicking Coil
Lighting Circuits
Lightning Arrester
Circuit Breaker
Kicking Coil
Controller No 1
Controller No.2
Running Points
Resistance Points
Forward
Reverse
Blow-out Coil
When Over-Head Trolley is not used Lightning Arresters and Kicking Coils are omitted
Car Wiring for K-27 Controllers
with two Motors
Metallic Circuit System

hence, the current passes to $T_2$ and to the other conductor rail. Throwing the main cylinder to the off-position does not interrupt this current though a movement of the reverse switch would. In order to avoid this condition, the K27 controller is provided with fingers $T_2$ and $E_2$ so that the current must pass through the main cylinder, and hence throwing the cylinder to the off-position interrupts this current. Also, the $E_2$ field wire runs through the No. *2* cut-out switch, so that if this motor becomes grounded and is cut out by throwing up the No. *2* cut-out switch, all connections between the No. *2* field and the $T_2$ terminal will be broken. This is not possible with an ordinary type K controller where the end of No. *2* field runs directly to the ground wire without being brought to the controller.

**70.** The K6 controller, Fig. 39, can be arranged for use on metallic-return systems, by making a few changes in the connections. Instead of connecting the $E_2$ and $E_4$ field terminals to the ground wire (or $T_2$ wire on a metallic-return system), as indicated in Fig. 39, they are connected to a wire running to post $E_2$ on the connection board of, say, No. *1* controller. The ground wire, shown in Fig. 39, is connected to the $T_2$ collecting shoe, and a wire is run between posts $E_2x$ on the two connecting boards. On the No. *2* connecting board, i. e., on the board to which the $E_2$ wire is not run, a connection is made between the $E_2$ post on the No. *2* cut-out switch, and the $T_2$ or $G$ post. The object of these connections is to allow No. *2* and No. *4* fields to be disconnected from the $T_2$ side of the circuit in case of a ground, as explained in connection with Fig. 42. The K6 controller is not, however, arranged like the K27, so that the main cylinder will open both sides of the circuit and break any current that may flow through motors No. *2* or No. *4* because of grounds.

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### L2 CONTROLLER

**71.** The **L2 controller** is intended for heavy high-speed interurban cars and will control two 175-horsepower motors. On account of the large current, the main cylinder

contacts, and also any other contacts that have to carry the current while the motors are in operation, are made unusually large by connecting a number of fingers in parallel

The L2 controller differs considerably from those of the K type, both in its construction and method of operation. The main cylinder simply cuts out the starting resistance and the changing over of connections from series to parallel is effected by a separate commutating arm or switch. While the commutating switch is changing from the series to the parallel position, the motor circuit is kept open by the main cylinder so that the commutating switch does not interrupt the current. Another feature is that the starting resistance is reduced by connecting resistance sections in parallel with the first section instead of cutting out sections, as in the K controllers.

**72.** Fig. 43 is a wiring diagram for L2 controllers as used on a car intended for operation either from an overhead trolley or from a third rail. Single-pole double-throw switches $t$, $t'$ are provided in each vestibule, so that the main car wiring can be connected either to the overhead trolley or third rail. Thus, when the switches are thrown to the upper position, the car being supplied from an overhead trolley, the third-rail shoes are dead. There are two reverse switches on each controller, each serving to reverse the armature connections of one motor. The reverse switches are operated by a single handle at the side of the controller which when thrown to the ahead-position makes contact segments $e$, $f$, $e'$, $f'$ occupy the position indicated by the vertical dotted lines, thus connecting $F_1$ and $A$ $A_1$, $F_1$ and $A$ $A_1$, etc. When the reverse switch is moved to the back-position, segments $e$, $f$, $e'$, $f'$ are rotated so that contact is made between $A_1$ and $F_1$, $A_1$ and $F_1$, etc., thus reversing the current in the armatures. The main cylinder, shown at the left, cuts out the starting resistance. There are 4 notches for the series combinations and 4 for the parallel, the last notch on each being a running notch. To throw the controller from the off-position to the last series notch, the operating handle is turned through half a revolution, thus moving the main

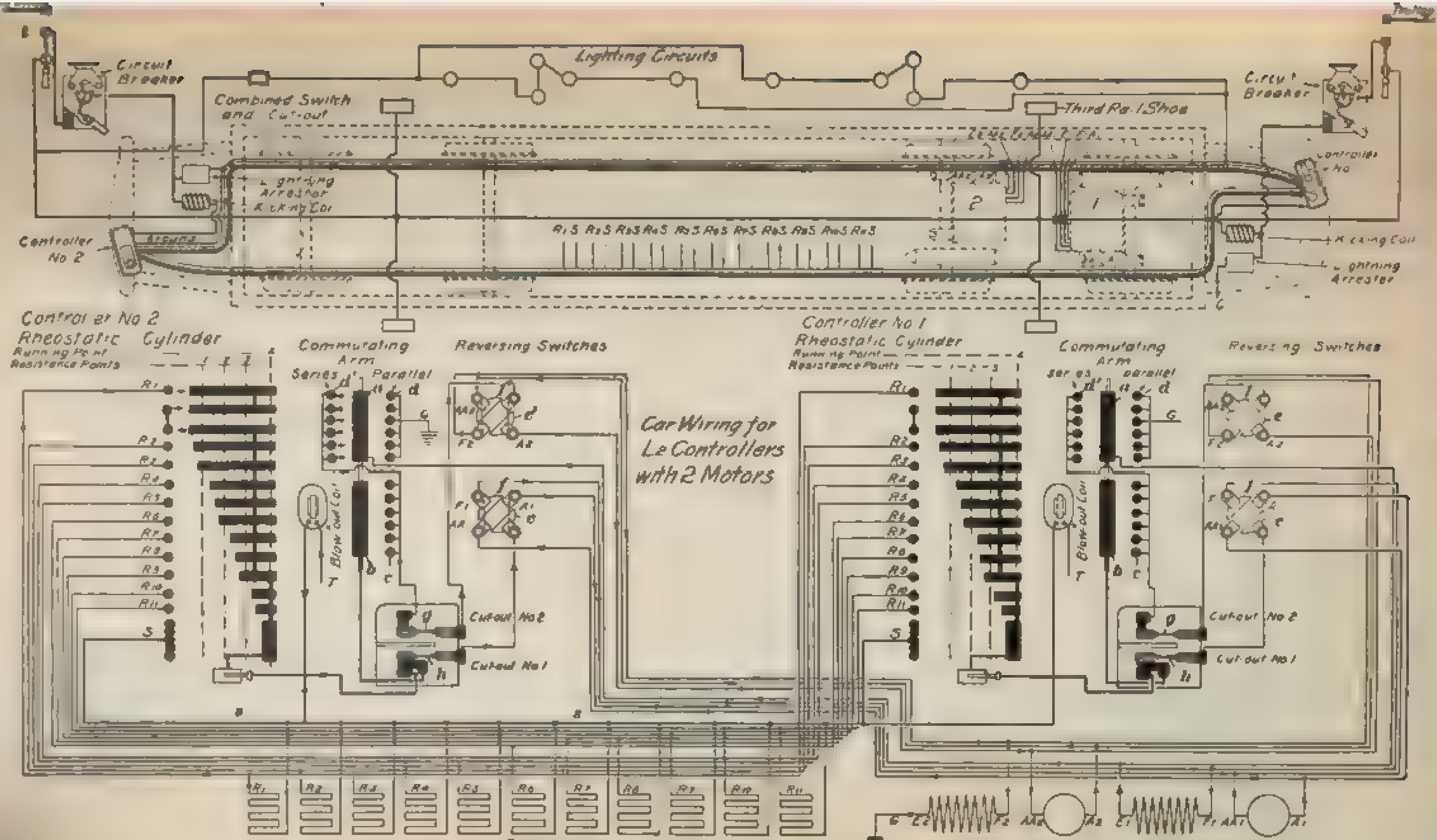

Lighting Circuits
Circuit Breaker
Combined Switch and Cut-out
Third Rail Shoe
Circuit Breaker
Lightning Arrester
Kicking Coil
Controller No 2
Kicking Coil
Lightning Arrester
Controller No 2
Rheostatic Cylinder
Running Point
Resistance Points
Commutating Arm
Series
Parallel
Reversing Switches
Controller No 1
Rheostatic Cylinder
Running Point
Resistance Points
Commutating Arm
Series
Parallel
Reversing Switches
Car Wiring for L2 Controllers with 2 Motors
Blow-out Coil
Cut-out No 2
Cut-out No 1
Blow-out Coil
Cut-out No 2
Cut-out No 1
Rheostats
Motor No 2
Motor No 1

FIG. 43

cylinder from the off-position to the position marked by the dotted line *1*. A further half revolution rotates the main cylinder backwards to the off-position so that when the handle has made a complete revolution and comes back to the starting point, the main circuit is again opened. As the handle is turned past the off-position, the commutating arm throws over to the parallel position before the main circuit is closed and, continuing the handle motion for another half revolution, the main cylinder again cuts out the resistance but this time with the motors in parallel. It thus takes a turn and a half of the operating handle to throw the power from the off-position to the last parallel position. The main drum is driven by means of a crank and sector-shaped gear, so as to give it a reciprocating motion, and the commutating arm is thrown from one side to the other by means of a cam, its movements being timed so that it opens or closes only when the current is cut off by the main cylinder. The commutating arm in Fig. 43 is represented by the segments *a*, *b*, insulated from each other and mounted so that, on the series positions *a* is in contact with fingers $d'$; on the parallel positions, *a* and *b* swing over so as to make contact with fingers *d* and *c*.

**73.** There are twelve series and parallel positions of the controller but only 4 notches on each; the path of the current on the first position is shown by arrows in Fig. 43 and is as follows: *T*–common resistance wire $S$–$R_1$–finger $R_1$–main cylinder–through cut-out switch No. *1*–$c$–$A_1$–$A$ $A_1$–$A_1$–$A$ $A_1$–$l$–$F_1$–$F_1$–$E_1$–segment *a* on commutating arm–fingers $d'$ (since the commutating arm is now in the series position)–cut-out switch No. *2*–$c'$–$A_2$ $A$ $A_2$–$A_2$–$A$ $A_2$–$l'$ $F_2$–$F_2$ $E_2$–ground. When the controller is moved to the next position, section $R_2$ of the resistance is connected in parallel with $R_1$, thereby reducing the total resistance in series with the motors. On the third position, or first series notch, there are three sections of resistance in parallel, finally on the last series notch, fingers *S* make contact with the main cylinder, thereby short-circuiting all the resistance. The operating handle has by this time made half a revolution, and as it is moved

quickly around for another half revolution, the main cylinder reverses its motion, thereby cutting the resistance back in, and finally opening the circuit. Just as the operating handle begins its second revolution the commutating switch throws over so that *a* makes contact with *d* and *b* with *c*, the path of the current on the first parallel position being: $T$–$S$–$R_1$–$R_1$–main cylinder–cut-out No. *1*–

$$\left\{\begin{array}{c} c\text{–}A_1\text{–}A\;A_1\text{–}A_1\text{–}A\;A_1\text{–}f\text{–}F_1\text{–}F_1\text{–}E_1\text{–}a\text{–}d \\ b\text{–}c\text{–cut-out No. }2\text{–}c'\text{–}A_2\text{–}A\;A_2\text{–}A_2\text{–}A\;A_2\text{–}f'\text{–}F_2\text{–}F_2\text{–}E_2 \end{array}\right\}\text{–}G$$

As the motion of the operating handle is continued for another half revolution, the main cylinder repeats the resistance combinations that it made during the first half revolution, and when the last parallel notch is reached, the resistance is short-circuited by fingers *S* again making contact with the main cylinder. Fig. 44 shows the combinations made on each of the series and parallel notches.

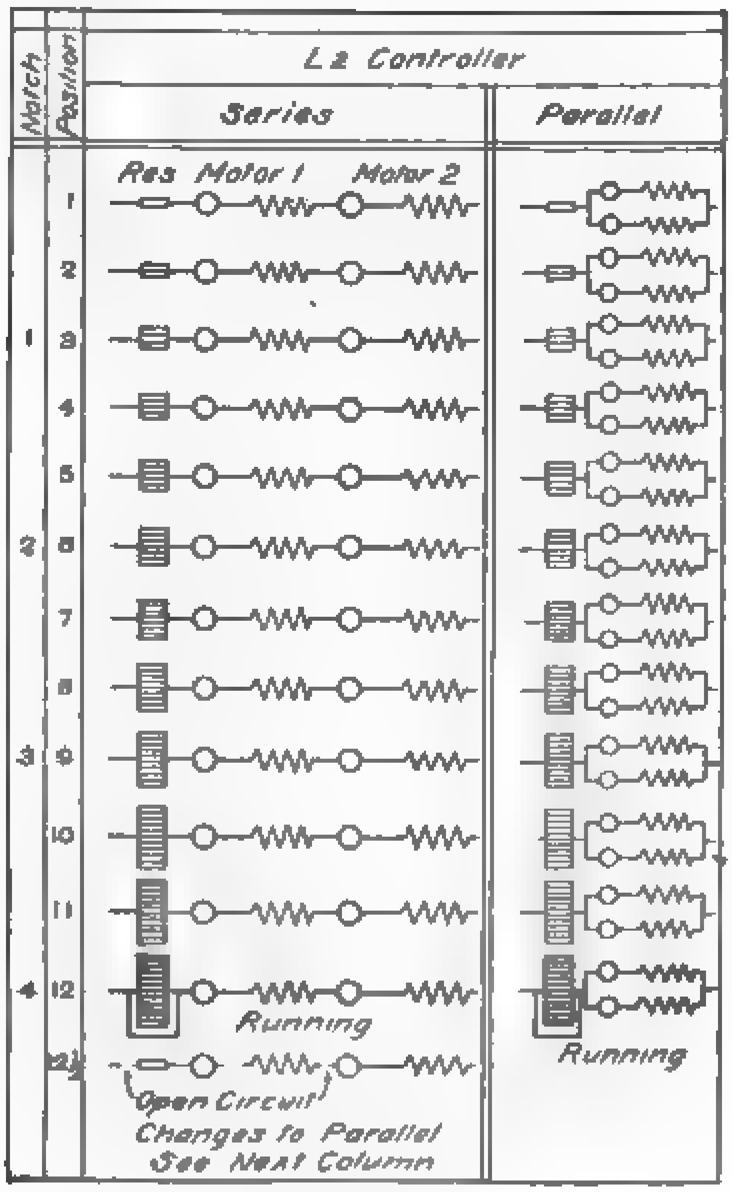



FIG. 44

**74. Cut-Out Switches.**—The cut-out switches simply open the circuit through the defective motor and if either motor is cut out, the commutating arm must be in the parallel position or there will be an open circuit. Thus, if motor

No. *1* is defective, it is cut out by opening switch blade *h*, and the controller is run on the last half revolution of the operating handle, in which case the commutating switch is on the parallel position and the current can take the path from cut-out No. *1*–*b*–*c*–No. *2* reverse switch and No. *2* motor to ground.

### L4 CONTROLLER

**75.** The **L4 controller** is similar to the L2 but is provided with four reverse switches, the controller being designed for operating four 100-horsepower motors. The cut-out switches are also slightly different, but the main cylinder and commutating arm are the same. Motors No. *1* and No. *3*, No. *2* and No. *4* are connected in parallel and the two groups operated in series or parallel as with single motors. Fig. 45 shows the connections for a single L4 controller, which are so nearly like those of Fig. 43 that it will not be necessary to explain them in detail.

## CONTROL OF ALTERNATING-CURRENT MOTORS

**76.** Alternating-current motors are specially adapted to interurban roads where the current has to be transmitted a considerable distance; hence, a high trolley pressure is used. This is stepped down by a transformer carried on the car so that the current supplied to the motors is at low pressure. It is frequently desirable to have the controlling apparatus arranged so that the cars can operate on either direct or alternating current, in which case switches must be provided for cutting out the transformer and making any other changes in connections that may be necessary. An arrangement of this kind allows interurban cars, that are normally operated by alternating current, to run over the tracks of connecting city roads operated by direct current.

**77. Westinghouse Control.**—Where a car is operated exclusively by alternating current, the speed of the motors can be regulated by varying the pressure, applied to the motors, by means of a potential regulator, or for small

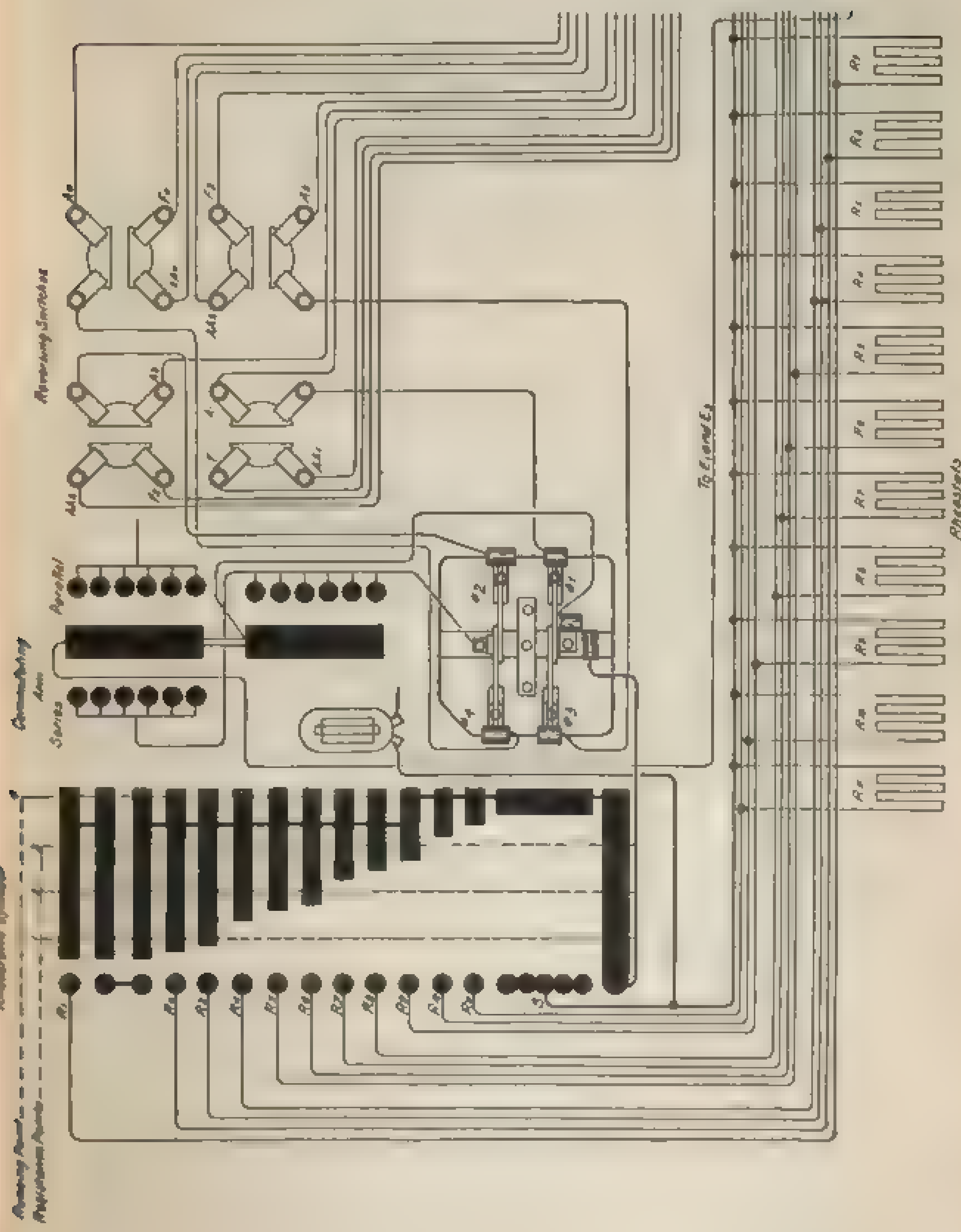
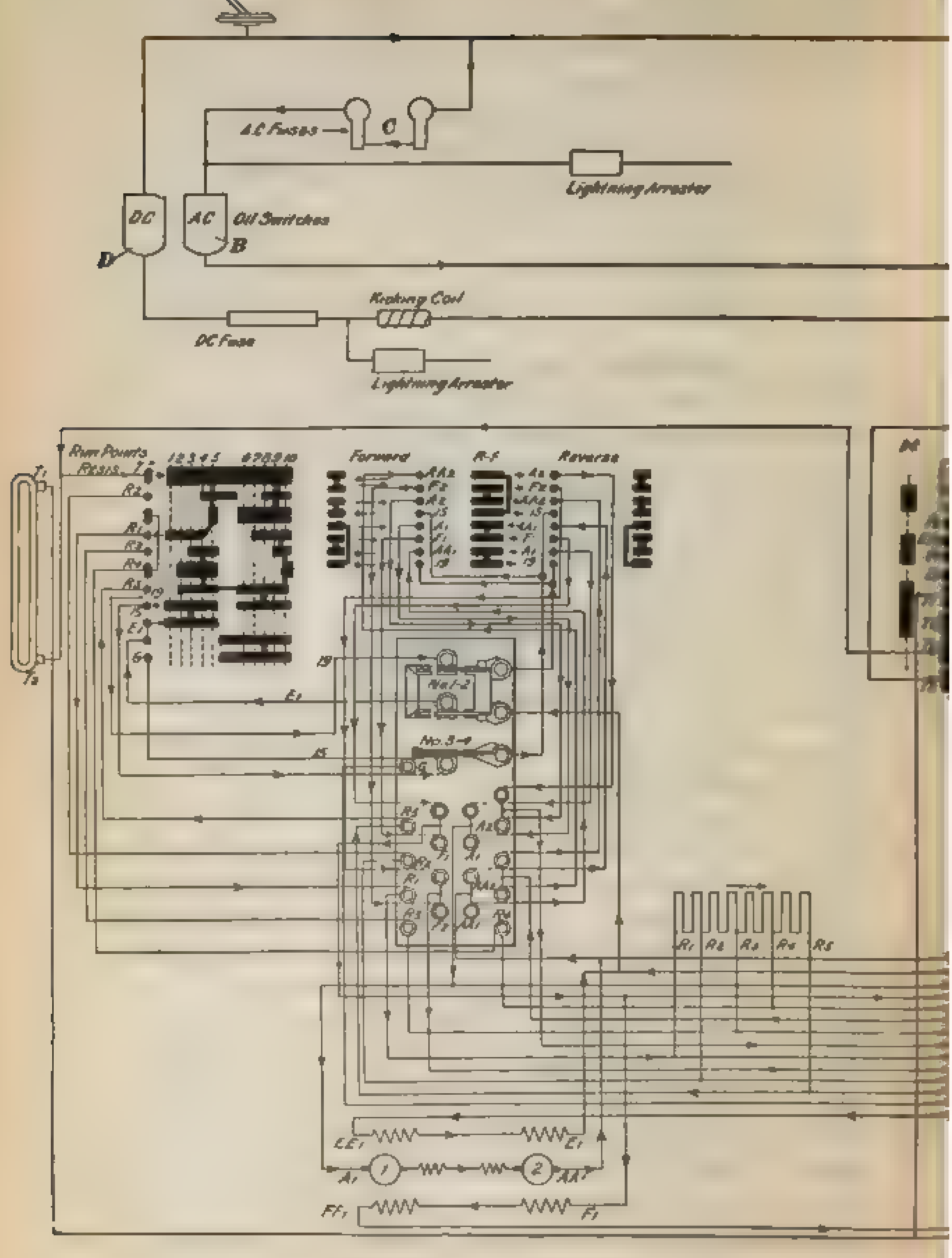



FIG. 45

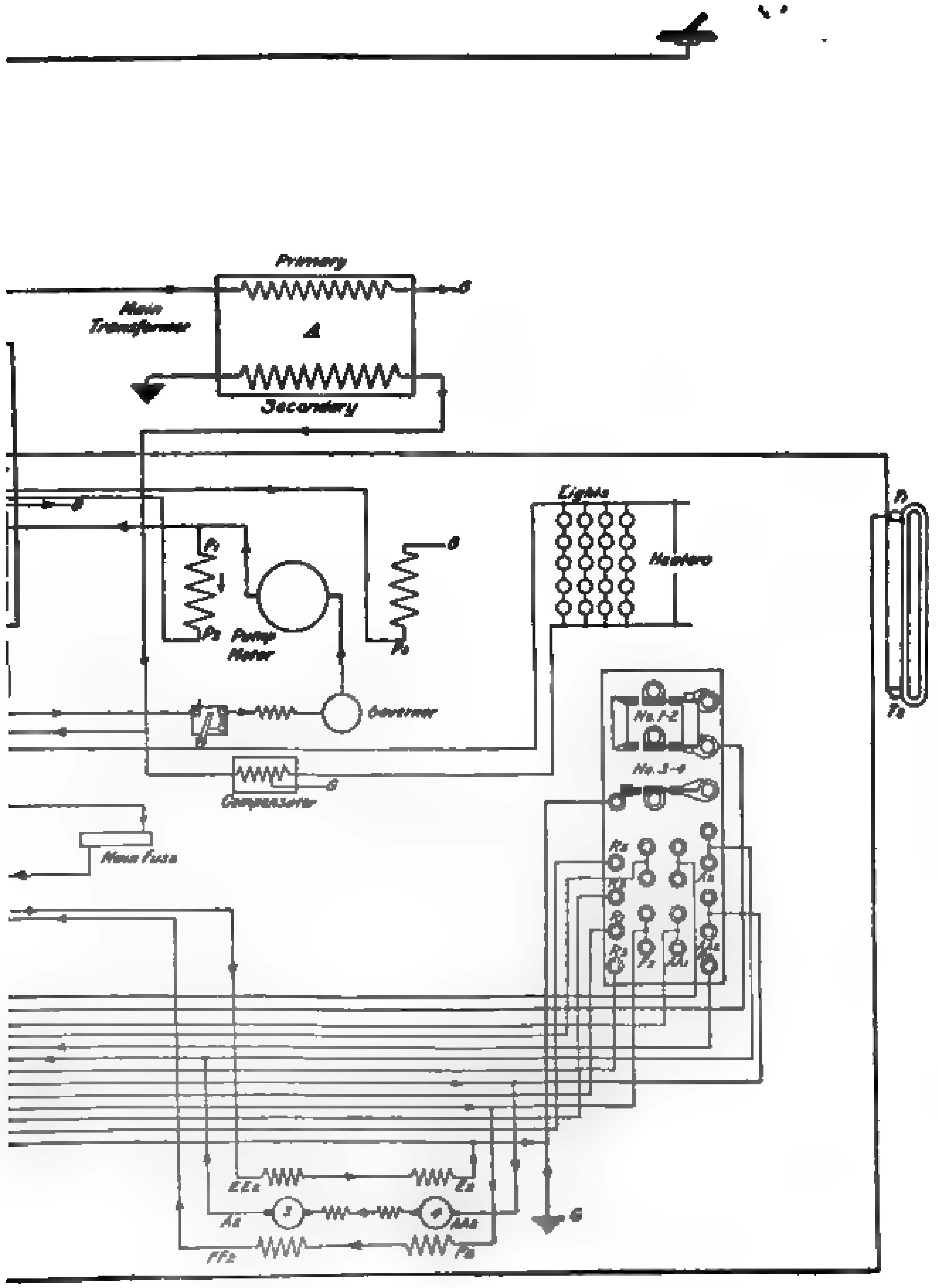
equipments, by providing the secondary of the step-down transformer with a number of taps that can be connected successively to the motor. This allows the applied pressure to be varied without the use of resistance and without the waste in power that resistance always causes.

Moreover, every point of the controller is a running point and the car can be run steadily on any of the intermediate speeds, since there is no resistance to overheat. The voltage for which the motors are wound is independent of the line voltage, because the pressure can be stepped down to any desired value.

Fig. 46 (*a*) shows the general plan of operation for a large two-motor equipment where the speed is changed by means of a potential regulator. The current from the trolley passes through an autotransformer *a*, *b*, and from the secondary part *b* current is supplied to the motors. In some cases, a regular transformer with separate primary and secondary coils is used, especially if the trolley pressure is high and it is desired to completely separate the controlling apparatus and motors from the high tension line. The motors are wound for 250 volts and have their fields and armatures connected permanently in parallel, as shown; a reverse switch *e* allows the direction of the current through the fields to be changed, thus reversing the motion of the car. The potential regulator *c d* is of the induction type consisting of a fixed secondary *d* and a movable primary coil *c* that can be rotated through a limited range. The voltage generated in *d* can be added to or subtracted from the normal voltage of the transformer secondary, thus allowing the voltage applied to the motors to be varied gradually from 125 to 250 volts. The primary of the induction regulator is moved by compressed air supplied from the air-brake pump on the car, and controlled by electropneumatic valves. For small cars, the arrangement is as shown in Fig. 46 (*b*); instead of a potential regulator, the equipment is simplified by providing the transformer with a number of taps *1*, *2*, *3*, etc. to which terminal *d* can be connected successively by a platform controller, thus increasing the voltage applied to the motors.



AC Fuses
C
Lightning Arrester
DC
AC
Oil Switches
B
D
Kicking Coil
DC Fuse
Lightning Arrester
Run Points
Resis.
Forward
R-F
Reverse
No.1-2
No.3-4


Primary
Main Transformer
Secondary
Lights
Heaters
Pump Motor
Governor
Compensator
Main Fuse
No. 1-2
No. 3-4

**78. General Electric Control.**—Fig. 47 is a diagram of car wiring for the control of four General Electric compensated single-phase motors arranged so that the car can be run on either alternating current at 2,200 volts, or direct

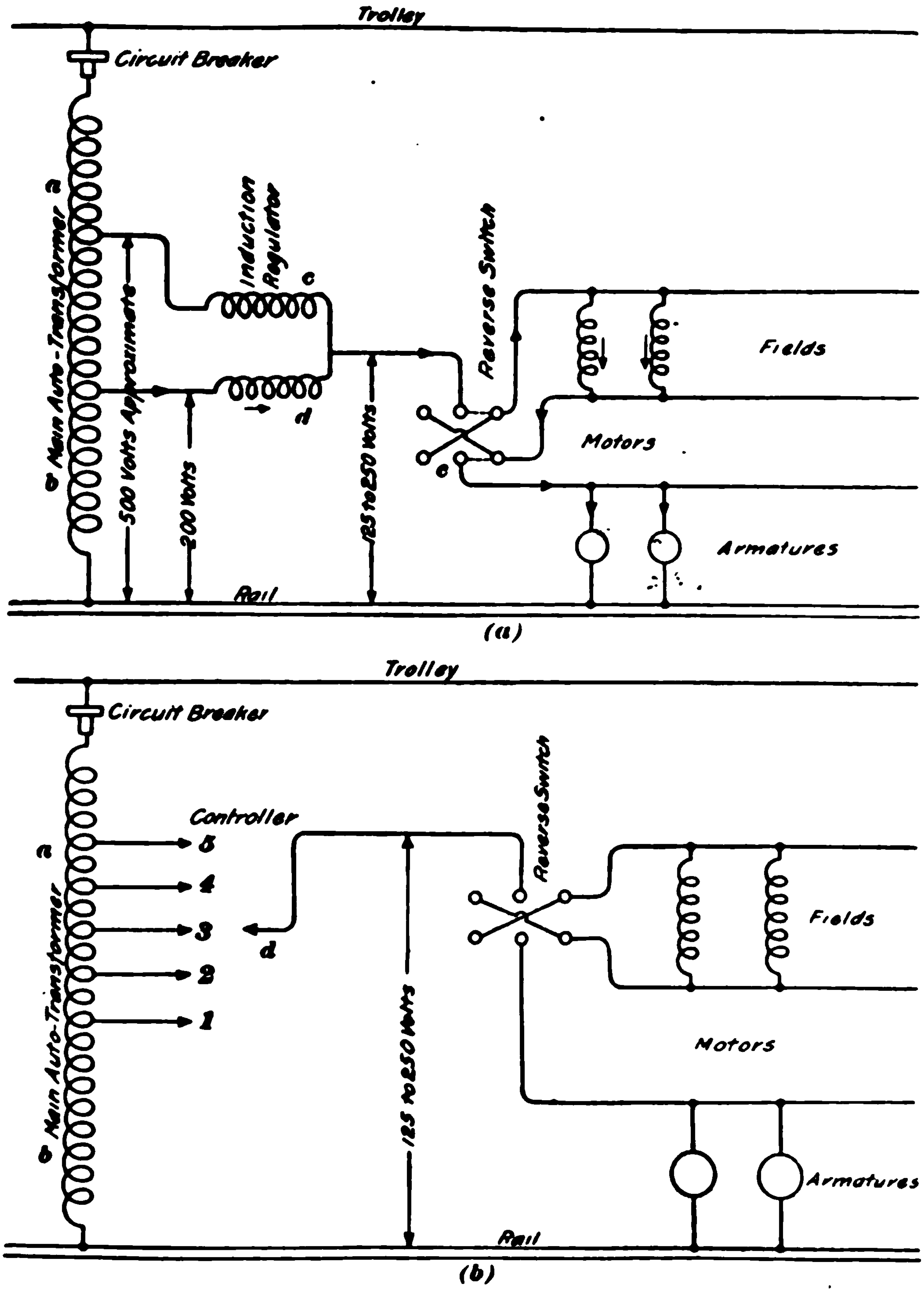



FIG. 46

current at 500 volts. On account of the use of direct current, resistance is used for the control of the motors, which are arranged in two pairs, two motors being connected

permanently in series for each pair. The regular series-parallel method of control is used and standard K28 controllers, as employed for the operation of direct-current cars, are connected to a separate commutating switch so that the connections can be changed from alternating current to direct current in a few seconds.

This scheme of control is not quite as economical as the potential-regulator method and does not give as many running speeds, but it has the advantage of using, for the most part, regular direct-current controlling apparatus, and the

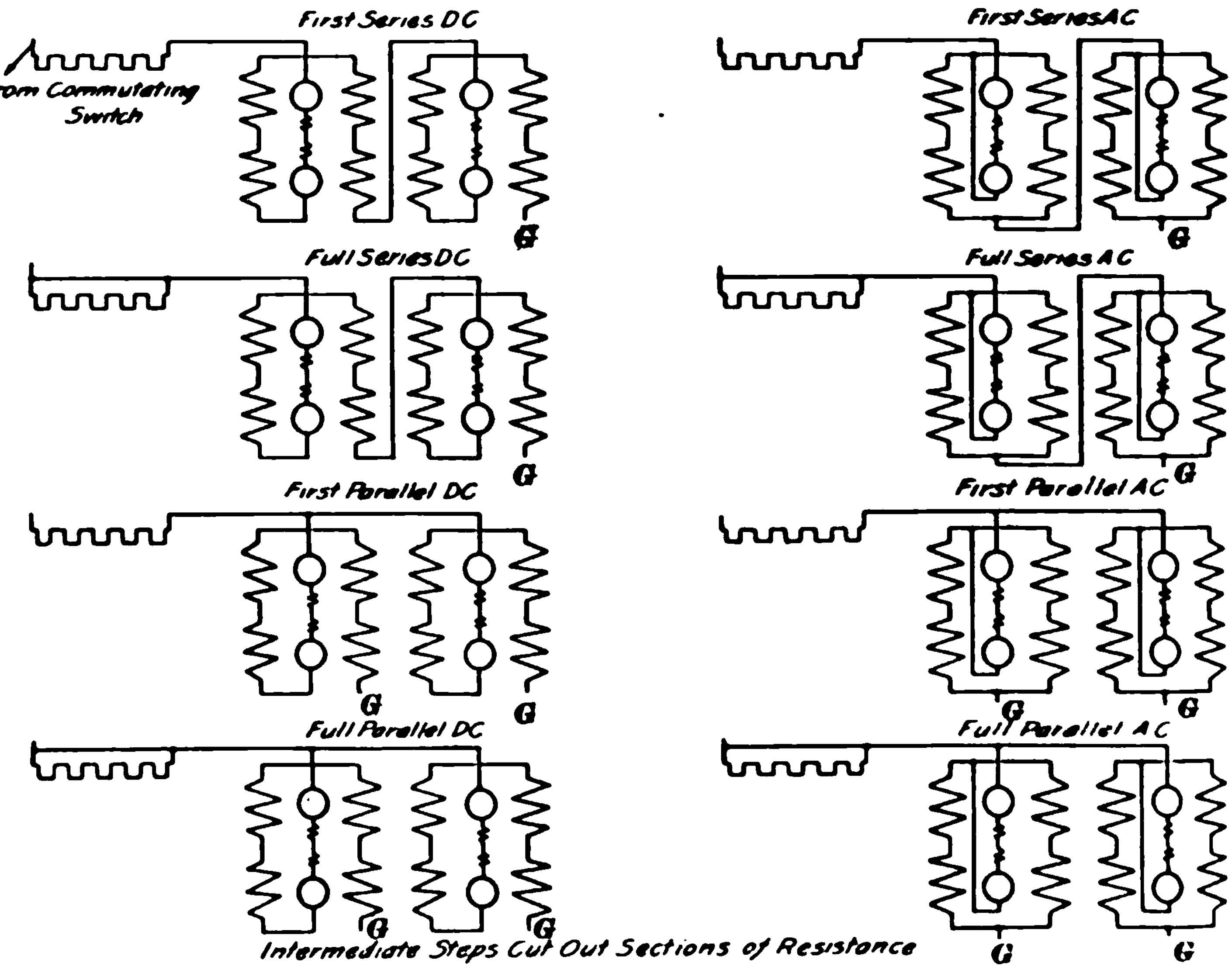



FIG. 48

additional apparatus required for alternating-current operation is small. The motors in Fig. 47 are wound for 200 volts alternating or 300 volts direct. *A* is the main step-down transformer for reducing the trolley pressure; in series with the primary are the oil switch *B* and fuses *C*. An oil switch *D* is placed in series with the direct-current connection also and both switches are interlocked with the commutating switch *E* so that the latter cannot be moved while either *B* or *D* is closed. The switches are also interlocked

so that only one switch can be closed at a time, thus precluding any possibility of trouble, on account of both currents being on at once. The commutating switch makes the necessary changes in field connections, and cuts out the step-down transformer, etc. when a change is made from alternating to direct and vice versa. In addition to the regular motors, the connections for the motor driving the air-brake pump are also shown, since this motor must likewise be changed over. In Fig. 47, the arrows represent the path of the current when the commutating switch is thrown to the *A C* position and the controller placed on the first notch.

In Fig. 48, the combinations on the most important positions for both direct and alternating current are given. With direct current, the four field coils on a given motor are in series, but when the change is made to alternating current the fields are connected two in series and the pairs placed in parallel. Also, when alternating current is used, it does not pass throughout the controller blow-out coil. The controller magnet core and pole pieces are not laminated; hence, alternating magnetism would cause heating.

# ELECTRIC-CAR EQUIPMENT

## MOTOR-CIRCUIT APPLIANCES

### TRUNK CONNECTIONS

**1.** By **electric-car equipment** is meant the several appliances by means of which the car is propelled, controlled, heated, lighted, and protected, as well as the system of wires necessary to connect the electrical devices. Some car equipments are more elaborate and complicated than others, due to widely different conditions of operation. To illustrate: on level roads employing small cars that run around a belt or loop, the car equipment may consist of a single controller, two motors, and hand-brakes; on other roads, where cars made up into trains must be accelerated to full speed and stopped in minimum time, the unit equipment may consist of four heavy motors with automatic devices for controlling the motive power, an elaborate system of high-speed automatic air brakes supplemented with air signals, and the most modern appliances for heating and lighting by electricity. The following discussion will be limited to a consideration of the average modern equipment, operated under ordinary conditions.

**2.** The **trunk connections** have to do with the wires and devices traversed by the motor current in its passage from the current collector—trolley wheel, third-rail shoe, or conduit plow, as the case may be—to the point or points where the main control device receives it for application to the motor circuit in various combinations. The motor ground connections are sometimes considered as part of the trunk system.

### TRUNK WIRE

**3.** The **trunk wire** is the wire part of the trunk connections, and takes its name from the fact that it conducts the total motor current of the car. It begins at the current collector and its path depends on the nature of the system on which the car is to be operated and on the location of the devices to be included. For example, Fig. 1 indicates the trunk wire on an ordinary surface car equipped with two hood switches and a fuse box; all devices are named and the current path is indicated by the order of the numbers. Fig. 2

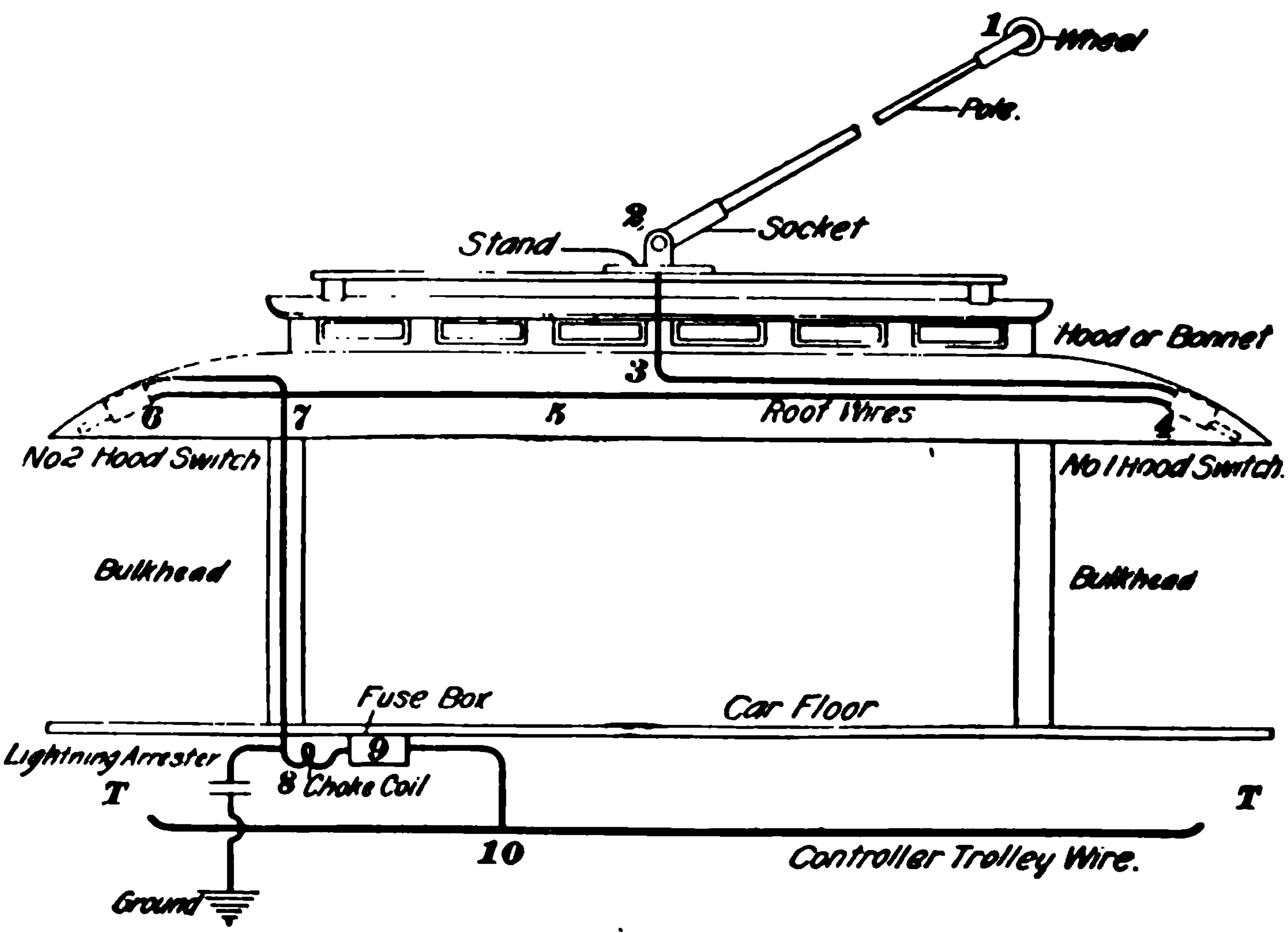



Fig. 1

shows the arrangement on cars intended to operate on both a third-rail and overhead ground-return system. The overhead construction includes two trolley stands, on opposite ends of the car, which may or may not be connected together; in either case a roof wire runs from each stand to a single-pole, double-throw, change-over switch in the vestibule or cab on that end. The third-rail construction consists of a spine wire running down the center of the under side of the car floor. The third-rail contact shoes on opposite sides of

the same truck are connected by a cross-wire that also connects to the spine wire, thereby connecting all four shoes together. A shoe is necessary on each side of each truck, because not only does the third rail contain gaps in places, but it frequently changes from one side of the track to the other. A car operating always from the same end on a road having a continuous contact rail always on the same side of the track would require but a single contact shoe. The continuation of the spine wire on both ends of the car is carried up through the bulkhead in some cases; in other cases, through metal conduit on the outside, to the other outside post of the change-over switch in the vestibule. From the handle post of the change-over switches the controller trunk wire runs to a circuit-breaker, located in the vestibule or under the car, and the other side of the circuit-breaker connects to the trolley post of the controller on that end. In some cases, a circuit-breaker or enclosed fuse is introduced in the spine-wire extension before it goes through the car floor, the idea being to have a safety device as near as possible to the contact shoes; but this idea is more often carried out by installing a fuse, called a *shoe fuse*, on the side of the truck above each contact shoe. The advantage gained by using the change-over switches is that the contact shoes of a car operating from the overhead wire are not alive. This is an important feature of safety at stations where passengers might come into contact with the third-rail shoes.

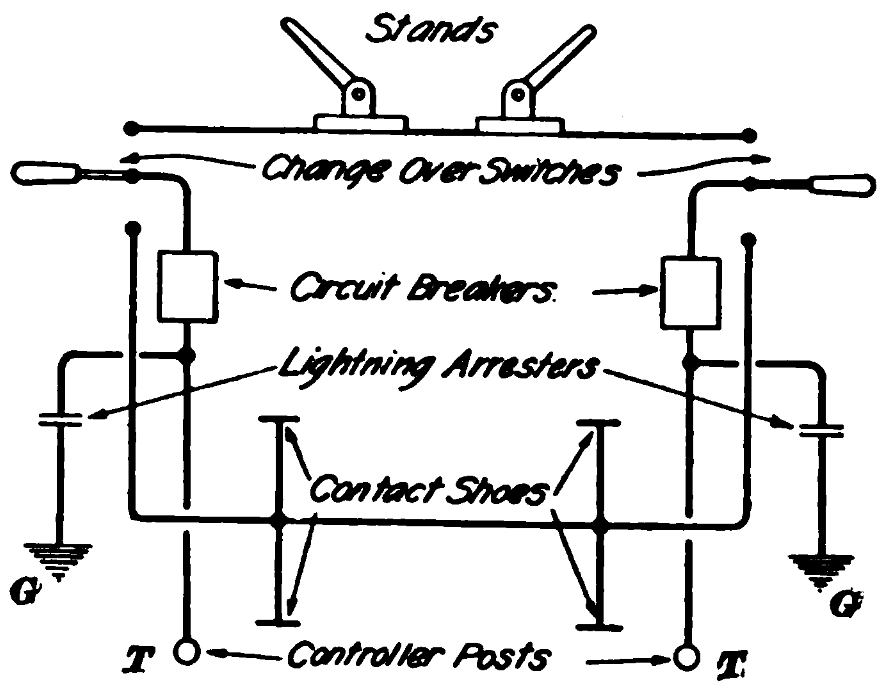


FIG. 2

**4.** Fig. 3 is a diagrammatic sketch of the trunk connections on a car equipped to operate on a conduit system. In this case, the trunk wire must traverse the distance from

the floor to the roof four times in order to reach the two overhead switches or circuit-breakers and return to the two controller trolley wires required in a metallic-return system. The bonnet switches are not necessary in this case, but are used to afford the motorman a convenient means of interrupting the current should the controller become disordered. On the open-conduit system, as operated in New York City, besides the motor switches installed in the bonnet there are installed under the car two circuit-breakers, two *ground switches*, so called because they were formerly the only means of cutting off the effect of grounds, and two fuses. All these devices are in series, so that the opening of any one of them will interrupt the current.

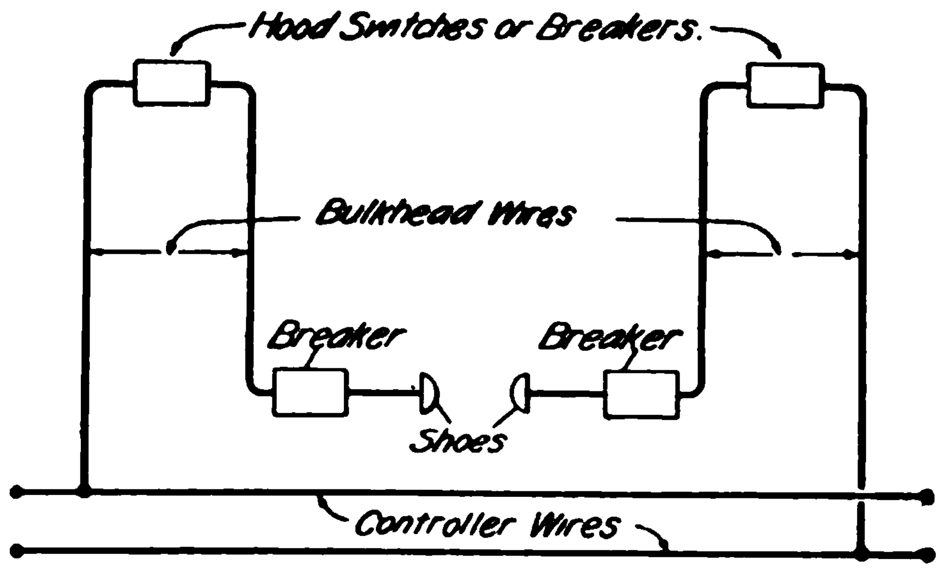



FIG. 3

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## OVERHEAD-TROLLEY FITTINGS

**5.** On ground-return overhead systems but one wire is used, so that short cars and long cars operating from the same end all the time require but one trolley device. Long cars that operate from both ends usually have two trolley devices, only one, however, being used at a time. On metallic-return overhead systems two trolley wires are used, thereby requiring a double, or duplicated, trolley device. On very long cars, there should be a double trolley device on both ends if the car operates from both ends.

The trolley device, or *trolley*, as it is commonly called, consists of a brass grooved *wheel* that turns on an axle supported in a suitable forked device, called a *harp*, that is riveted to the *trolley pole;* the pole being clamped in the *socket* of a *spring base* pivoted to a *foot* that is screwed to a board fastened to the car roof.

### THE STAND

**6. The Nuttal Stand.**—Fig. 4 shows a type of trolley stand of which there are many in use. Base *a*, pivoted to foot *b*, which is let into the trolley board, carries an upright extension that serves as a bearing for axle *o*, around which socket *G* can rock in a vertical plane. Wings *f*, *f*, integral with the socket casting, engage tension rods *e*, *e*, of

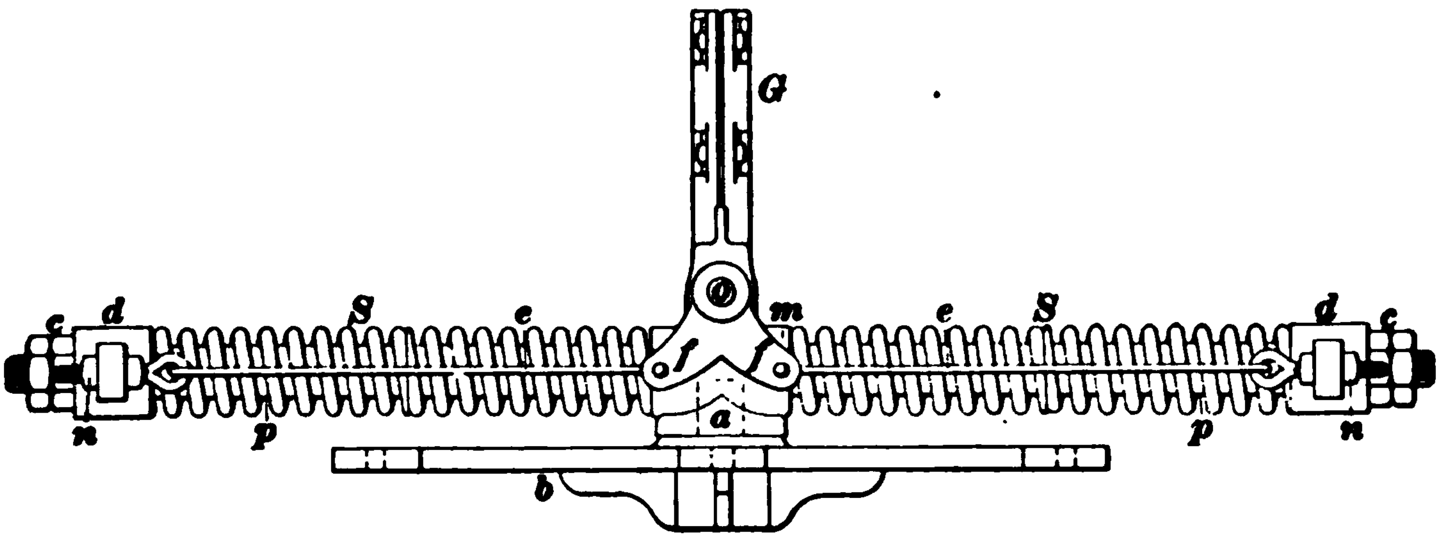


FIG. 4

which the other ends engage castings *d*. Movement of socket *G* in a clockwise direction will cause right-hand tension rod *e* to pull on its casting *d*, thereby compressing spring *S* mounted on right-hand arbor *p* and resisting the movement of the socket. Counter-clockwise movement of the

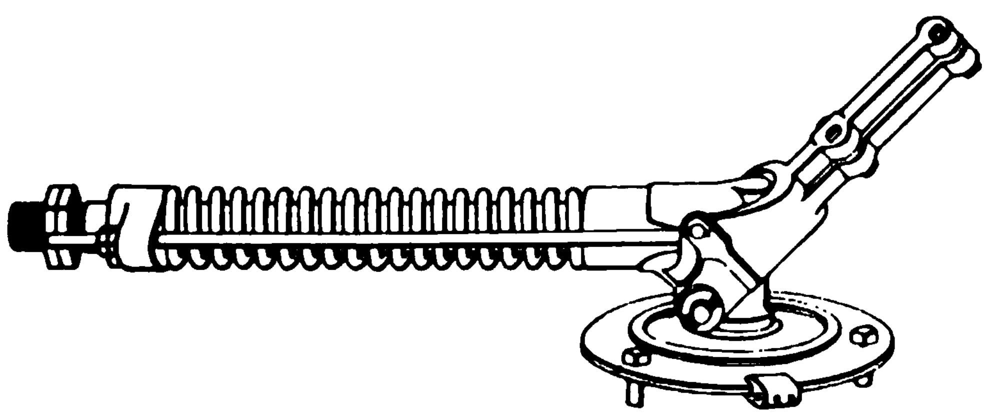

FIG. 5

socket will put the left-hand spring *S* into action. It follows, then, that if a pole under tension leaves the wire, the successive action of first one spring and then the other lessens the shock that the device would otherwise get.

**7. The Union Stand.**—Fig. 5 shows the union stand, which, having but one spring, cannot be rocked over. The

characteristic feature of this stand is that the same spring serves as a tension spring and as a recoil spring to take the shock when the wheel flies off the trolley wire.

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### POLE, HARP, AND WHEEL

**8. Pole.**—The pole proper, which is from 12 to 15 feet long, is about 1½ inches in diameter at the large end, and


FIG. 6

holds this diameter for about 2 feet, when it tapers gradually to a diameter of 1 inch. Most poles are steel, hard drawn by a special process, and offer great resistance to bending. A slight bend in a pole is generally straightened by using a post with a hole in it as a vise and bending by hand; but severe bends should be taken out by sledging cold. A pole should not be heated to straighten it, as the character of the steel is generally such that the part heated becomes soft and easily bent. Fig. 6 gives an idea of the straight and tapered part of a standard pole.


FIG. 7

**9. Harp.**—The harp in which the wheel turns is the forked device secured to the small end of the pole. Harps are made of malleable iron or brass and are of various sizes and shapes, depending on local conditions. Fig. 7 shows several styles of harp, all of which are provided with two springs *a*; the end of each spring bears against the side of the trolley wheel, thereby preventing the bearing surface

between the wheel and axle from carrying appreciable current. The main requirements of a harp are that it be as light as practicable and of smooth contour, to minimize the chances of its catching in the line work and pulling it down.

**10. Wheel.**—The trolley wheel is a device on which much experimenting has been done to determine the best shape of wheel and the best composition of metal consistent with long life of the wheel and trolley wire. Some wheels wear out more quickly than others, and some are harder on the trolley wire. A wheel that is too soft will wear out very soon; on the other hand, a wheel that is too hard or that has a poorly shaped groove will scrape the trolley wire at curves and turnouts. Almost all roads do a certain amount of experimenting to decide what shape and metal are best

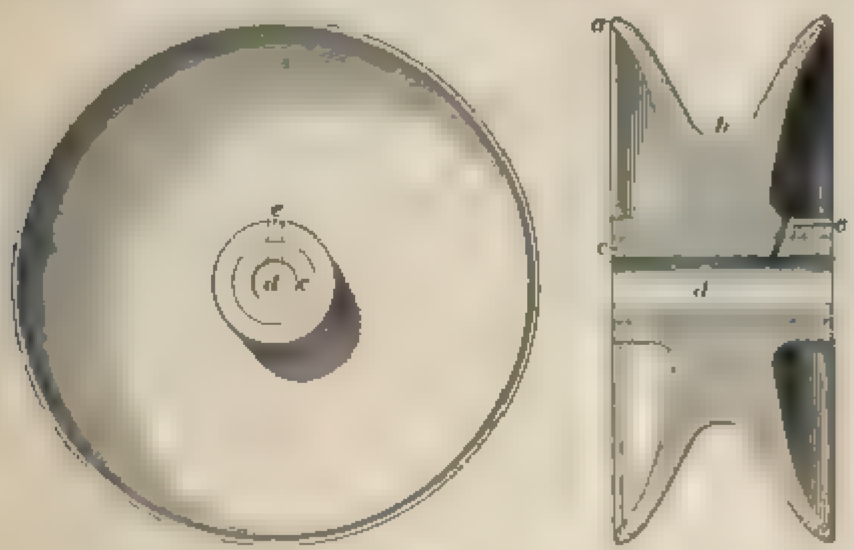

FIG. 8

adapted to the overhead construction. A good lesson can be learned from a careful observation of worn out wheels; some wheels wear out most in one place and some in another; the same make and shape of wheel will wear differently on different branches of the same road.

Fig. 8 shows a type of wheel, of which *a* is the flange; *b*, the groove; *c*, the bushing or bearing; *d*, the hole through which the axle passes; and *e*, the hole for oiling. On the more modern types of trolley wheel, of which a number are shown in Fig. 9, the bearings are of the self-lubricating type.

The diameter of trolley wheels varies from 4 to 8 inches, according to the speed of the service, the most common size being about $4\frac{1}{2}$ inches in diameter. The last of the series of wheels shown in Fig. 9 is called a **sleet wheel**, because it is used to cut sleet off the wire. The wheel is cast with holes in the flanges and the machining of the grooves leaves the holes with sharp edges that cut the sleet. In the absence of a sleet wheel it is customary to remove the ordinary wheel and use the harp as a cutter.

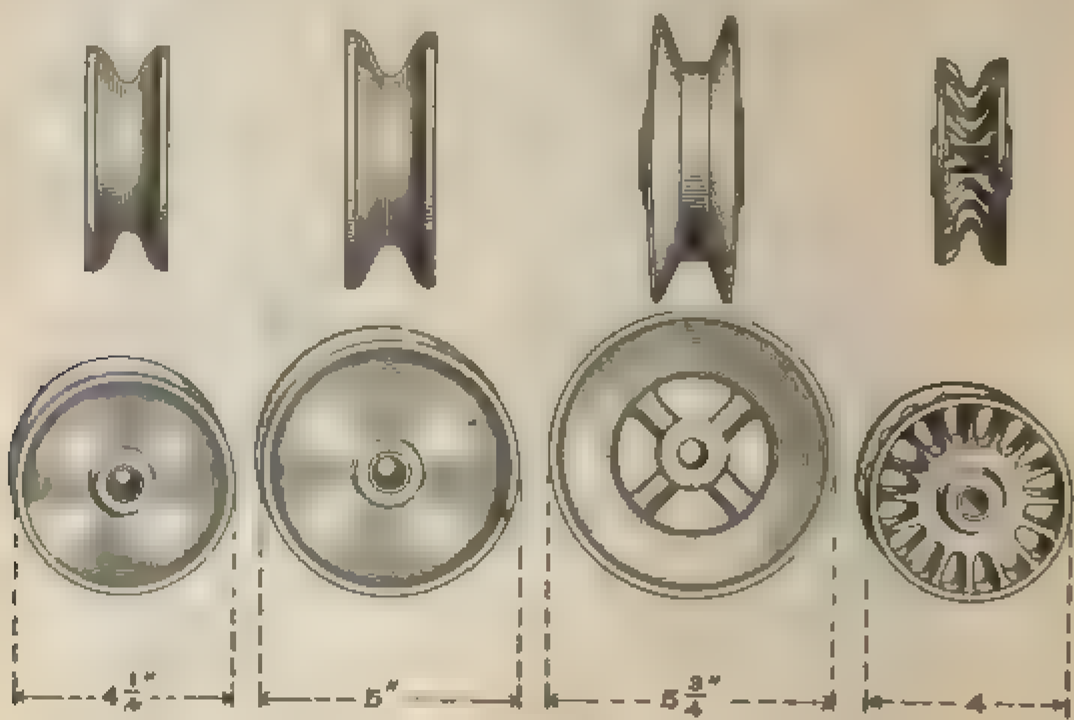


Fig. 9

**11. Pressure of Wheel on Wire.**—The pressure of the wheel against the trolley varies from 12 to 20 pounds, according to local conditions and the speed at which the car is to run. Too light a pressure will permit the wheel to jump off at kinks and turns, while excessive pressure will wear all parts unnecessarily and cause trouble in replacing a wheel that has jumped the wire. Under ordinary conditions, the pole should make an angle of about 45° with the car roof and the upward pressure on the wire should be about 15 pounds.

## SWITCHES AND BREAKERS

### SWITCHES

**12. Remarks.**—The motor switches used on cars to interrupt the motor circuit are of the same general type, whatever may be the nature of the system on which the car is to operate. On ground-return systems they are installed under the car hoods, and are called **hood switches.** In slotted conduit work the hood switches are also installed for reasons of safety, but in addition similar switches are installed under the car, as near as possible to the plow shoes.

**13. Type of Switch.**—Fig. 10 shows a motor switch in very general use; it is of the magnetic blow-out type.

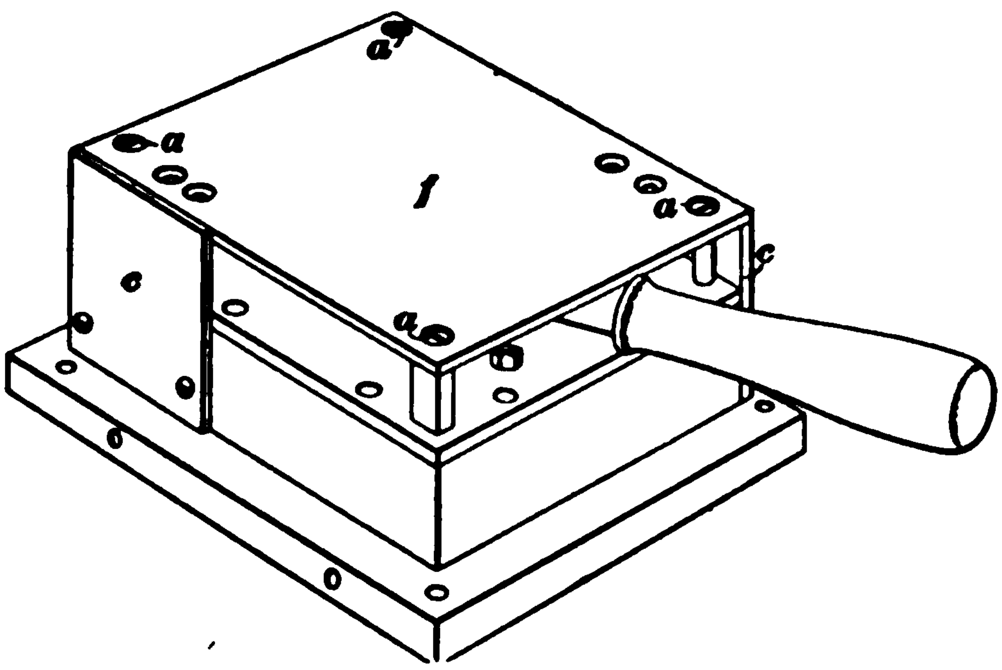


FIG. 10

Fig. 11 shows the top plate removed, exposing the connections. In Fig. 11, $e+$ is the roof wire leading to the switch and $e-$, that leading from it. The switch blade turns on pin $p$ as a center, and $M$ indicates the magnetic blow-out coil in the bottom of the case. Switch blade $B$ is of iron and covers part of the magnetic circuit through which coil $M$ sets up lines of force that pass across the current-breaking contacts. When the switch is closed, as in the figure, current enters at $e+$; to reach pin $p$, part of the current passes from the terminal jaw $a$ through the switch blade, and part passes through coil $M$, which is of very low resistance. The

total current passes through the right-hand end of blade *B* to reach jaw *d*. On opening the switch, the instant jaw *a*

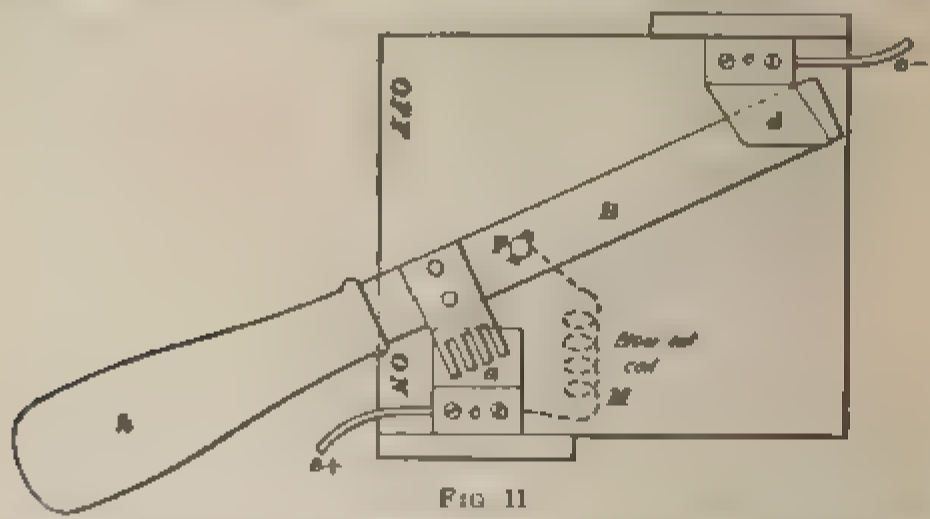

FIG. 11

breaks contact with the switch blade, the entire current must pass through blow-out coil *M*, thereby establishing a strong magnetic field that ruptures the arc at *d*.

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CAR CIRCUIT-BREAKERS

**14.** In some cases, **circuit-breakers** have entirely replaced hood and ground switches; in others, one of the two hood switches has been replaced by a circuit-breaker; while in still others, two ground switches have been supplemented by two circuit-breakers connected in series with the switches and located alongside of them. All car circuit-breakers have facilities for operating them by hand, like a switch, and the only advantage of using a circuit-breaker and motor switch in series is to obtain the automatic safety feature of the breaker without buying two breakers. Car circuit-breakers should always be adjusted in the position that they are to occupy when on the car, otherwise gravity may introduce an error in the setting.

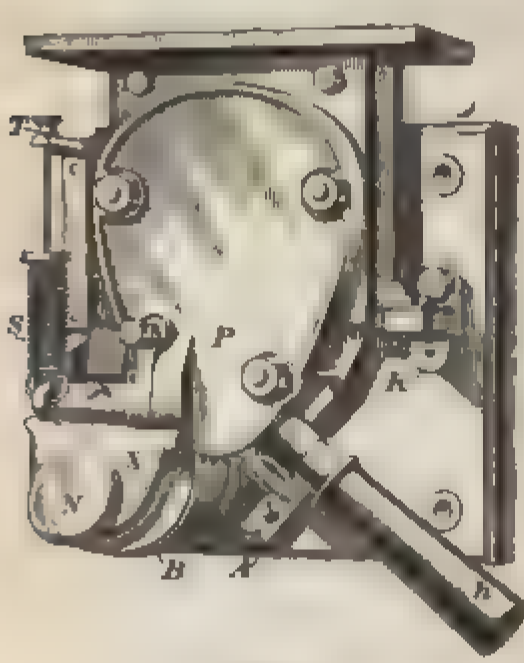


FIG. 12

**15. General Electric Car Circuit-Breaker.**—Fig. 12 shows a type of surface-car circuit-breaker made by the General Electric Company. When used as a hood breaker it is enclosed in a box from the front end of which the handle projects, as indicated in Fig. 13.

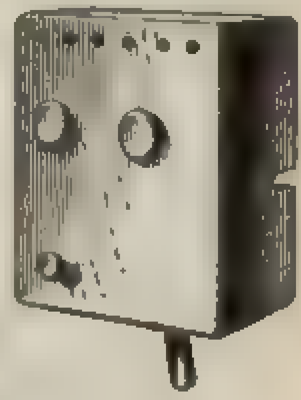


FIG. 13

In Fig. 12, *A* and *K* are the breaker terminals and *B* the operating coil, which also provides magnetism for extinguishing the arc. Coil *B* pulls armature *X* against spring *S* whenever the current exceeds that for which the breaker is set. The operating current value is adjusted by means of nut *T*. The iron

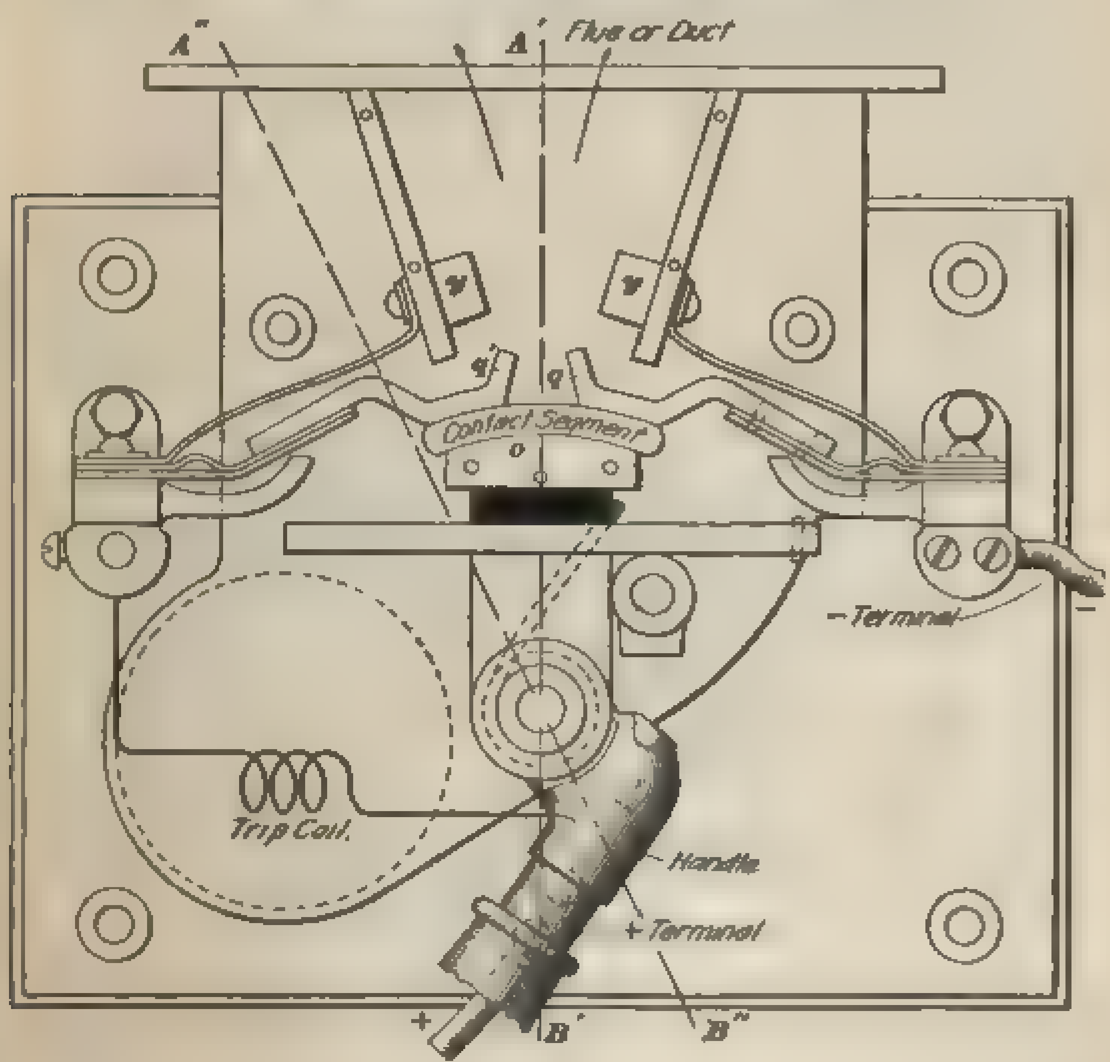



FIG. 14

plate *P* and a similar one back of it are magnetized by the current in coil *B*, and as the arc occurs between these two

poles, it is promptly extinguished by the magnetic field existing there.

Fig. 14 shows the movement of parts during operation of the breaker. The contact segment engages fingers $q$, $q'$ so that the breaker is closed. When the breaker operates, the center of the contact segment $o$ takes a position coinciding with line $A'' B''$, thereby leaving an open circuit between fingers $q$, $q'$. The arc is forced up by the magnetic field to auxiliary contacts $y$, $y$, between which it is broken without damage.

Fig. 15

**16. Westinghouse Type of Car Circuit-Breaker.** Fig. 15 is a general view of a surface-car breaker made by the Westinghouse Company. The screw for adjusting the operating current value is shown at $t$; this screw must be pulled out a little and turned while it is held out, in order to

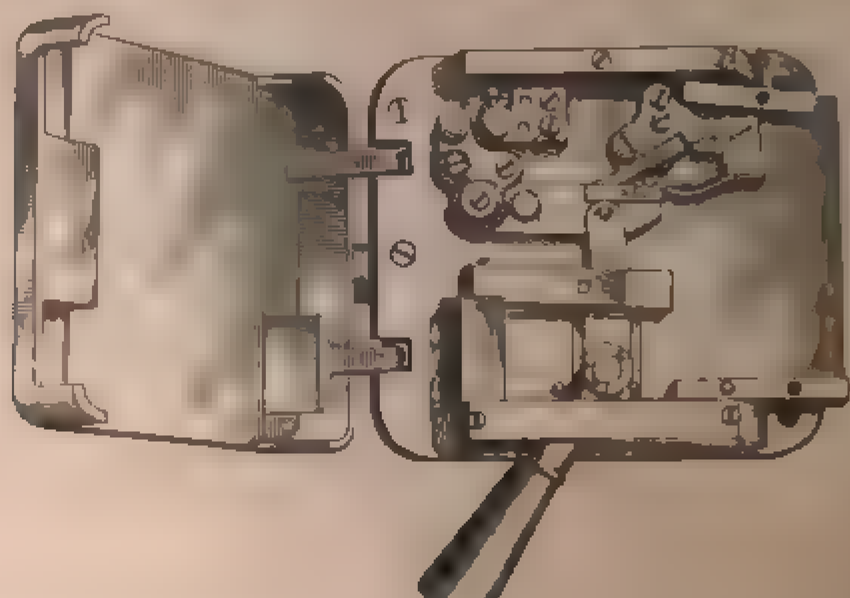


Fig. 16

adjust the tension on the spring that regulates the tripping point. Fig. 16 shows the breaker with the circuit-breaking parts exposed, and Fig. 17 indicates the movement of the circuit-breaking parts from the on- to the off-position. When handle *a* is to the left, the breaker is held closed, because spring *l* keeps togglejoint *c d* beyond the dead center, but no further than permitted by a projection on the under side of slide *f*.

To operate the breaker by hand, handle *a* must be forced to the right, thereby bending the togglejoint to the left and permitting spring *l* to snap blade *e* and all attached parts to the dotted position. Automatic operation is effected by an electromagnet, the coil of which is energized by the current and pulls armature *g* to the left, thereby bending the togglejoint to the left, as in the case of hand operation, whenever the current exceeds the value for which the breaker is set. The secondary contacts *o* and *p* are in parallel with the primary contacts *m*, *n* when the breaker is closed. When the breaker operates, *m* leaves *n* before *o* leaves *p*, thereby breaking the current at contacts *o* and *p*, which are cheap and easily replaced. The final break takes place in a powerful magnetic field that promptly extinguishes the arc.

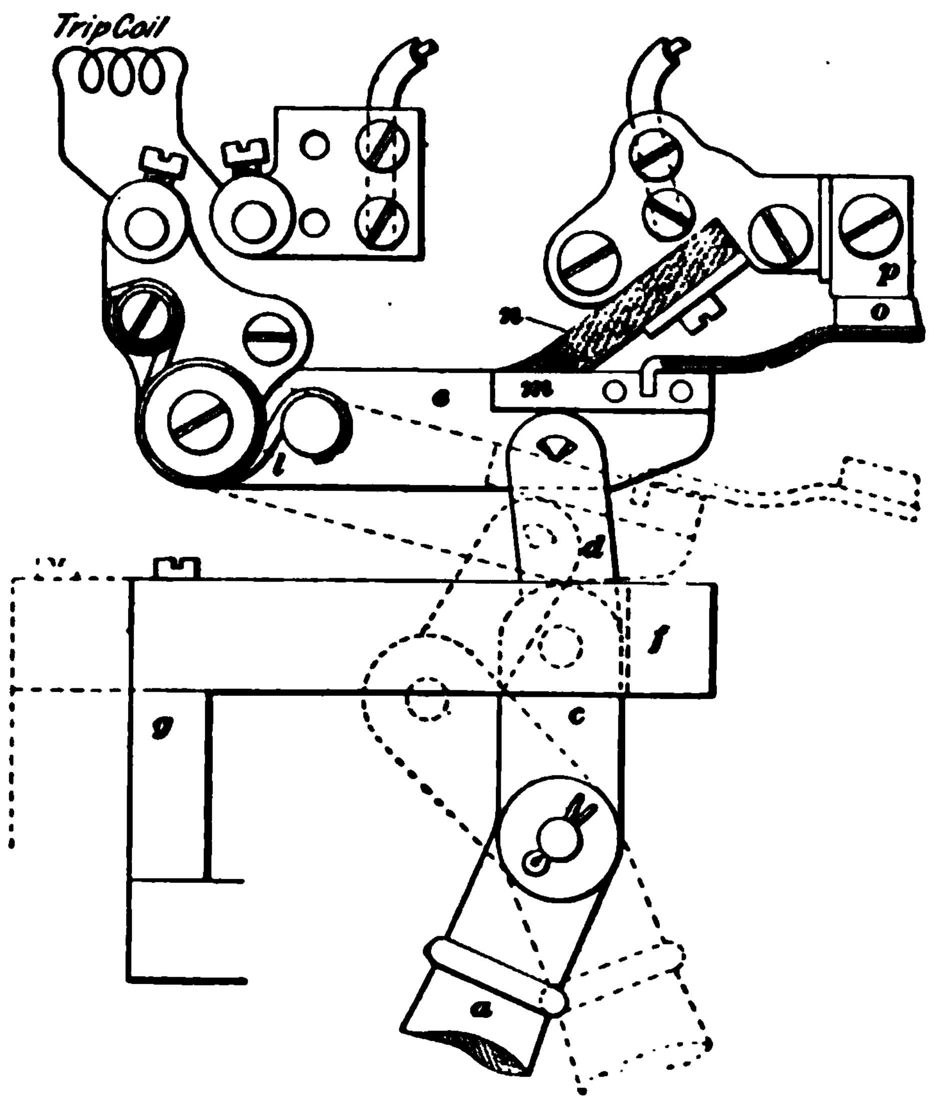


FIG. 17

## FUSES

**17.** At one time, the fuse alone was used to protect motor circuits from excessive currents. On many roads, the circuit-breaker has superseded the fuse, because, for protection under given conditions, a circuit-breaker can be set to act at a closer overload value with a fair degree of certainty than a fuse; and in cases of operation, it is much easier and quicker to close a breaker than to replace a fuse. Circuit-breakers kept in proper repair and adjustment are certainly more reliable than fuses, from the protection point of view.

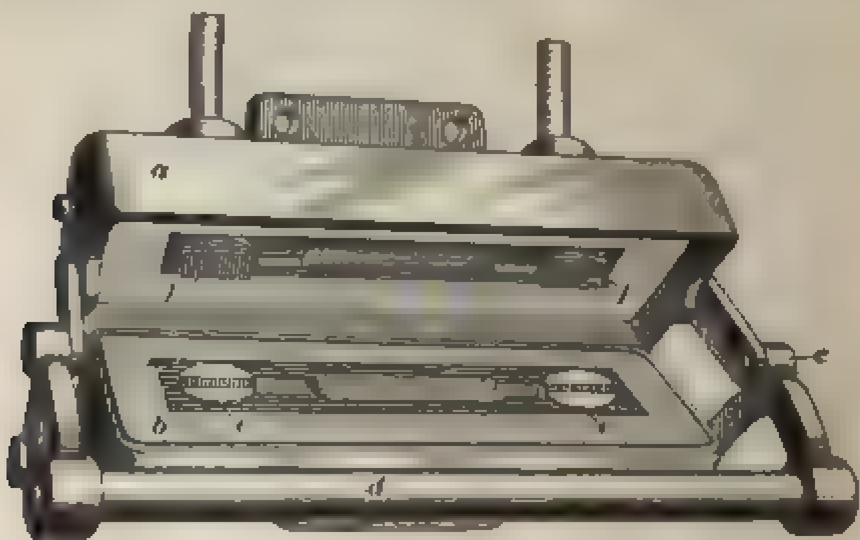



FIG. 18

On some large roads there seems to be a tendency to revert to the practice of using fuses, at least in conjunction with circuit-breakers, because in many cases of failure of the circuit-breaker the controller has blown up with disastrous results, as regards suits for damages. A circuit-breaker in series with a fuse is a good combination on a car, as the breaker is normally more of a protection than the fuse, but the fuse will prevent accidents should a short circuit occur and the breaker fail to operate because of being stuck.

## WESTINGHOUSE CAR FUSE

**18.** Fig. 18 illustrates a type of fuse box introduced by the Westinghouse Company. The asbestos-lined iron box is divided into two parts *a* and *b*, hinged together through a

togglejointed construction *c* provided at the front with the handle bar *d*, the raising of which brings the two halves *a*, *b* together. In the bottom half are copper terminals with V-shaped grooves *e*, into which a piece of copper-wire fuse of suitable length is dropped. Registering with the V-shaped grooves *e*, *e* in the bottom terminals are V-shaped tongues *f*, *f* in the top terminals. On bringing the top and the bottom halves of the case together, by pulling up handle bar *d*, the two pairs of V-shaped jaws automatically clamp the fuse in circuit. The advantages of this type of fuse box are low maintenance cost and the care and quickness with which a fuse can be replaced without liability of shock; the lower terminals are dead when the case is open.

The size of copper wire to be used as a fuse to protect any equipment of given horsepower can be obtained as follows:

**Rule.**—*Multiply the total horsepower of the equipment by 70, and in the circular-mils column of any wire table find the nearest number to the product so obtained.*

EXAMPLE.—What size of copper wire must be used to protect an equipment of two 50-horsepower 500-volt railway motors?

SOLUTION.—The total horsepower of equipment is $2 \times 50 = 100$. $100 \times 70 = 7{,}000$. The nearest number to 7,000 in the circular-mils column of a B. & S. wire table is 6,529, which corresponds to a No. 12 B. & S. wire. Ans.

---

## ENCLOSED FUSES

**19.** Figs. 19 and 20 illustrate fuses that, on account of the fuse metal being enclosed, are called **enclosed fuses.** The hollow cartridge *a*, Fig. 19, is made of some tough, fibrous, insulating material and is provided with copper heads or terminals *b*. The fuse metal occupies the hollow space, and its two ends connect to terminals *b*; the space surrounding the fuse is filled with finely divided powder, such as plaster of Paris mixed with powdered borax, which, when the fuse melts, fluxes with the molten metal, rendering it non-conducting and preventing the formation of an arc. The fuse as a whole is installed in spring jaws *c*, connected with terminals *d*, by means of which the fuse is connected

in the circuit to be protected. In Fig. 19, the parts are simply mounted on a slate base, but in Fig. 20 the whole device is enclosed in an asbestos-lined iron box *a*, provided with a lid *b* held closed by latch *c*. The trunk wire passes to

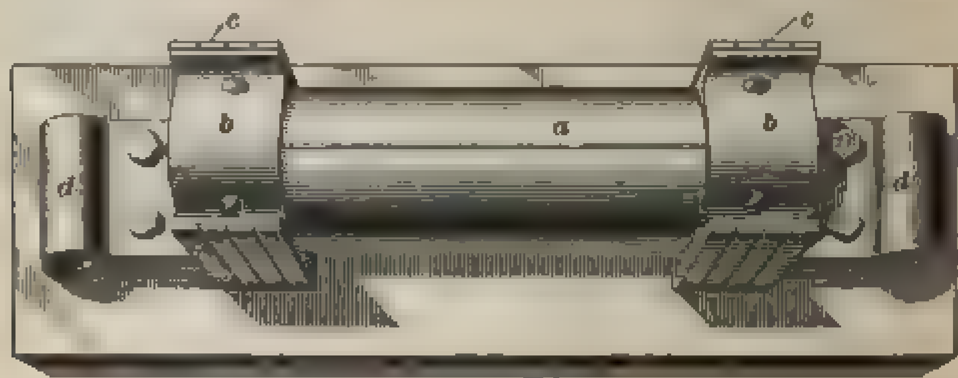



FIG. 19

fuse-block terminals *d* through hollow insulating bushings *e*. Some enclosed fuses, instead of having contacts to fit spring jaws, have ordinary eye terminals that must be secured to their seats with screws. The screw connection is probably

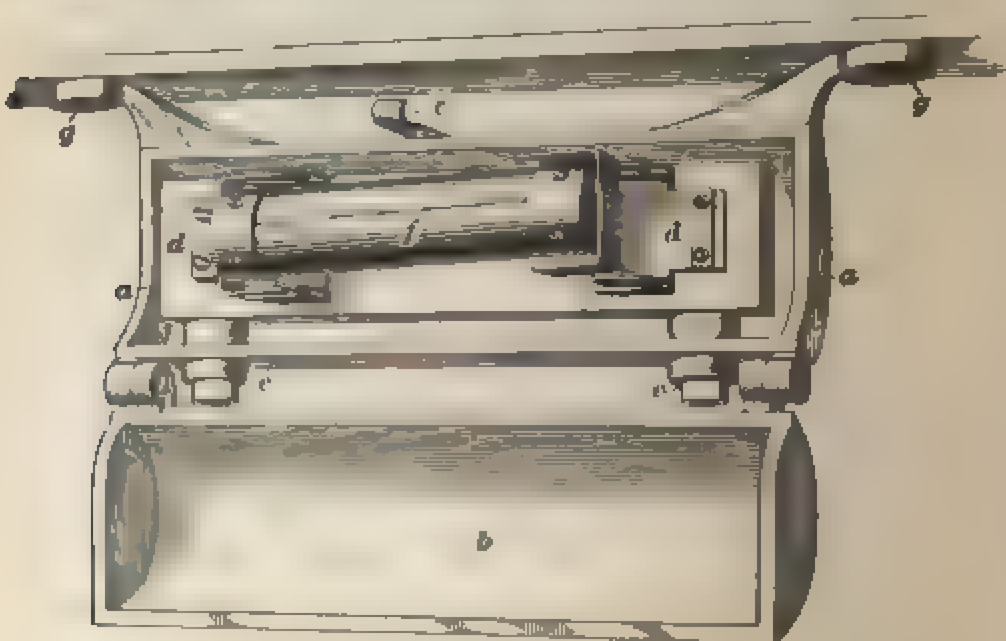



FIG. 20

more mechanical, but the spring-jaw construction is sufficiently safe and is much more convenient.

To tell whether or not the enclosed fuse is blown, a small wire *f*, called the *telltale*, is connected in parallel with the

enclosed fuse but on the outside of the cartridge. When the main fuse blows, the telltale burns out also. The enclosed type of fuse can be installed without danger of burn or shock, by taking hold of the cartridge at the middle.

## LIGHTNING ARRESTERS

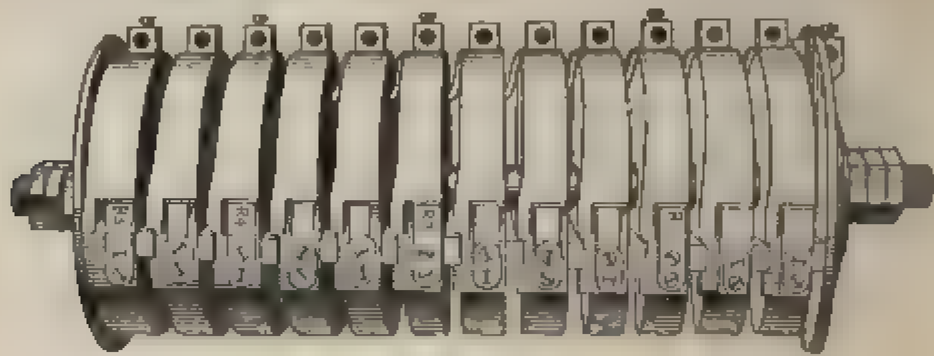
**20. Lightning arresters** used in car work are practically the same as many of the arresters described in a preceding section. A car arrester must have facilities for extinguishing the arc due to the line current following the lighting discharge across the gap. Owing to the jolting and vibration to which a car arrester is subjected, the spark points cannot be set for as thin an air gap as on a stationary arrester, because of their liability to jolt together and produce a short circuit. The arrester must be enclosed in a wooden box, which protects it from the mud and water slung by the car wheels.

On cars that operate entirely in a tunnel or on a conduit system, no arresters are needed on the car, but exposed line feeders are protected in the usual manner; this is also the case on elevated third-rail systems. On overhead metallic-return systems, both ends of the motor circuit must be protected by an arrester. On ordinary surface trolley cars but one arrester is used on the trolley end of the motor circuit; two would be better as a factor of safety should one get out of adjustment.

An arrester having parts depending on gravity for action should be installed vertically, otherwise it cannot work. Where an external choke coil is used, or an arrester has three terminals, one of which leads to an internal choke coil, care must be taken to connect the arrester so that the choke coil is in series with the motor circuit and not in series with the air gap.

## RESISTANCE COILS

**21. Westinghouse Starting Coil.**—Fig. 21 illustrates a type of car resistance coil, or so-called **diverter**, made by the Westinghouse Company. It is of the well-known



(a)

(b)

Fig. 21

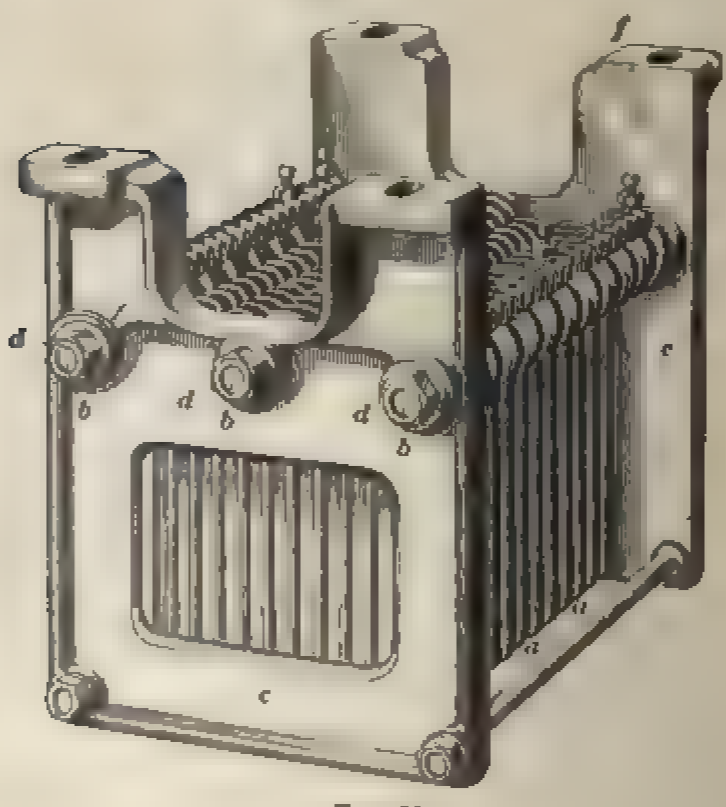


Fig. 22

barrel type wound with band iron, with mica insulation between layers. It is a decided improvement on older types in that the ventilation facilities are much better, on account of

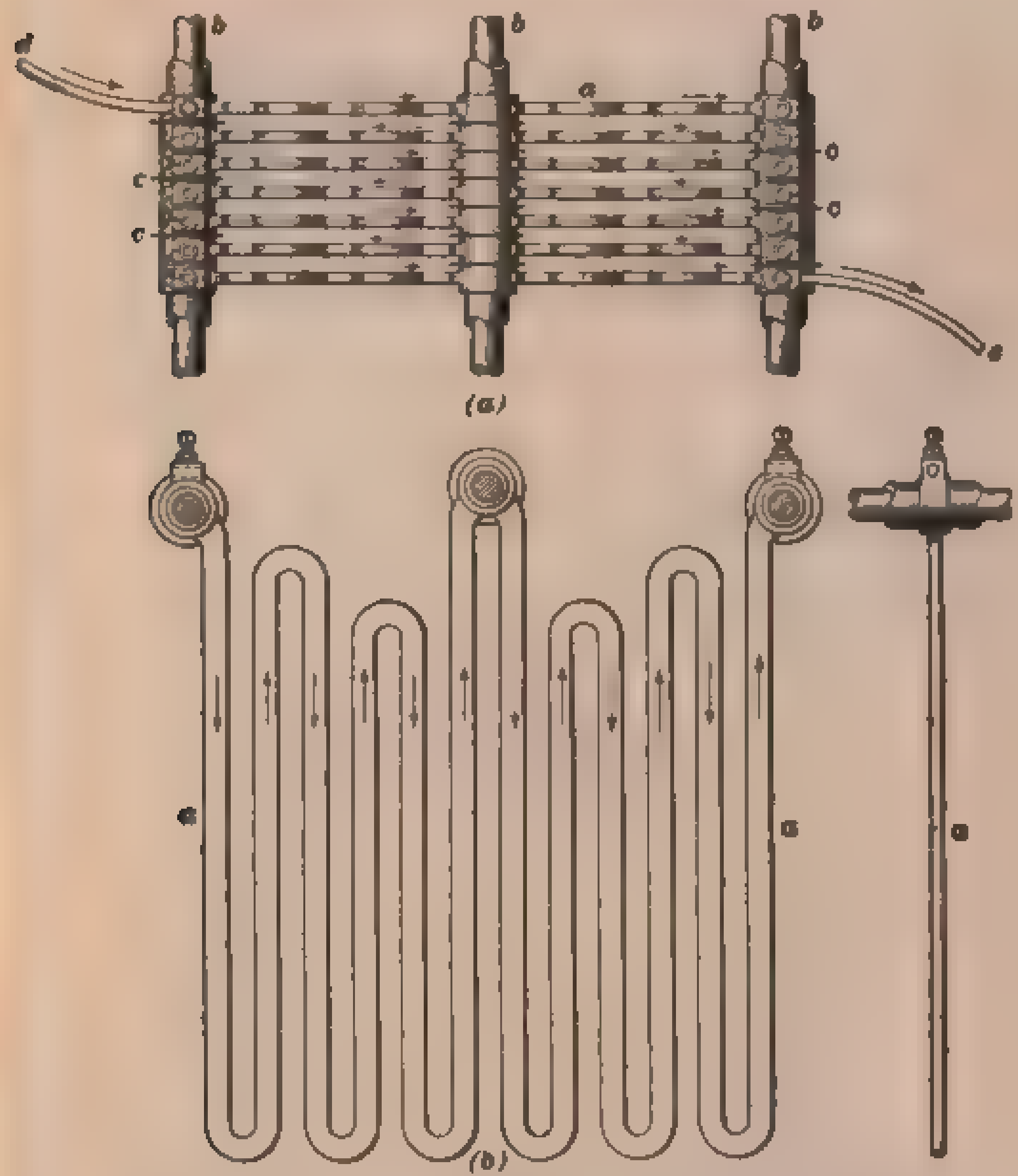


FIG. 23

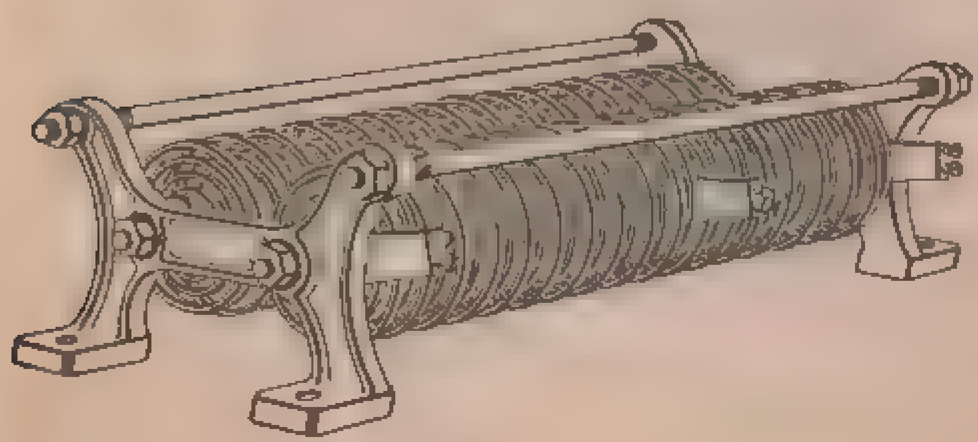


FIG. 24

an air space being left between the sections of the winding; (*a*) shows the coil and (*b*) one of the iron hangers used for suspending the coils from the car sill.

22. **General Electric Grid Coil.**—Fig. 22 is a view of the General Electric type of **grid coil**, of which Fig. 23 (*b*) shows the shape of the cast-iron grid and (*a*) the zigzag path of the current through the grids. The grids *a, a* are assembled on insulated studs *b, b*, end plates *c, c*, Fig. 22, being then put on and the whole compressed into a solid mass by drawing up on nuts *d* at both ends. Feet *f* are for hanging the coil from the car floor. On the middle stud *b*, Fig. 23 (*a*), all the grids are separated from each other by mica insulating washers. On the two outside studs *b*, however, considering any two adjacent grids, they touch each other on one stud, but on the other stud they are separated by a mica washer.

FIG 25

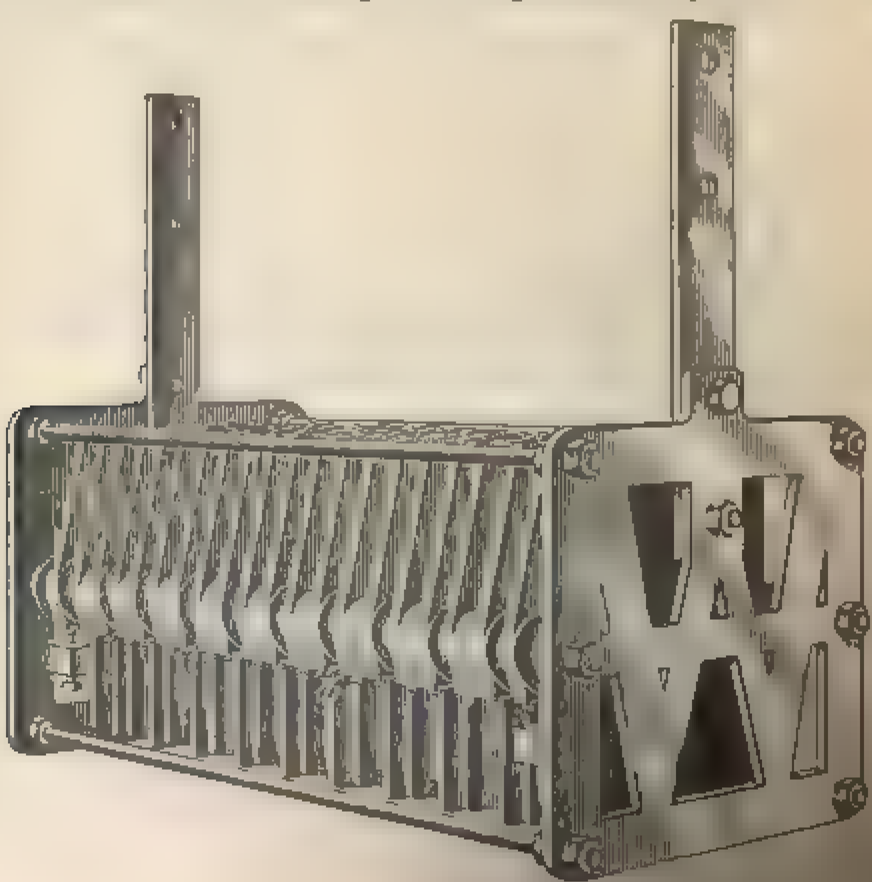


FIG 26

The current entering at one end is thus compelled to take zigzag path to the other end, a

coil shown represents the unit starting coil used in heavy traction work, a complete starting coil of any desired capacity being composed of the required number of unit starting coils connected in series or parallel, or both. The coil used for surface trolley-car work is of the same construction, but is longer and may contain several sizes of iron.

**23. Lundie Grid Coil.**—Fig. 24 is a general view of the **Lundie grid coil,** and Fig. 25 shows the shape of grid used. The method of assembly is the same as that of the General Electric, except that contact between adjacent grids is improved by inserting a soft copper washer between them.

**24. Westinghouse Grid Coil.**—Fig. 26 is a general view of the grid coil. The general method of assembly is the same as that of the preceding examples, with the exception that adjacent grids are connected by means of a brass plate screwed to both of them, as shown at *a*.

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## CAR-WIRING REQUIREMENTS

**25.** Strictly speaking, the name **car wiring** includes all wires necessary to the operation of a car, but it is generally understood to apply only to the wires that interconnect the controllers, motors, resistances, and the ground; that is, the wires and dependent taps included in a consideration of the wiring cable of an ordinary car. The connections of the heaters and lamps are referred to independently as the heater wiring or the lamp wiring, while the stretch of circuit extending from the trolley stand to the controller trolley wire is referred to as the trunk wiring. On cars of moderate weight, it is customary to run the wires in a canvas hose or in conduit extending from one controller to the other, the hose being slit at intervals to let out taps that connect the several car wires to their respective controlling, operating, or safety devices. On heavy cars involving the use of large currents, the car wires are not bunched together in a hose, but are run separately on a smooth insulated surface, specially prepared for them, if necessary, and afterwards covered with specially molded insulation.

Fig. 27 illustrates a molded insulation, called *electrobestos*, used for this work. In ordering such expensive insulation, great care must be taken to get a correct plan of the proposed layout of the car wires, for mistakes in regard to it will be expensive. The car for which the samples of electrobestos shown were made had its under surface prepared within the working area by laying a sheathing of hard maple, this wood being comparatively free from acid; nailed

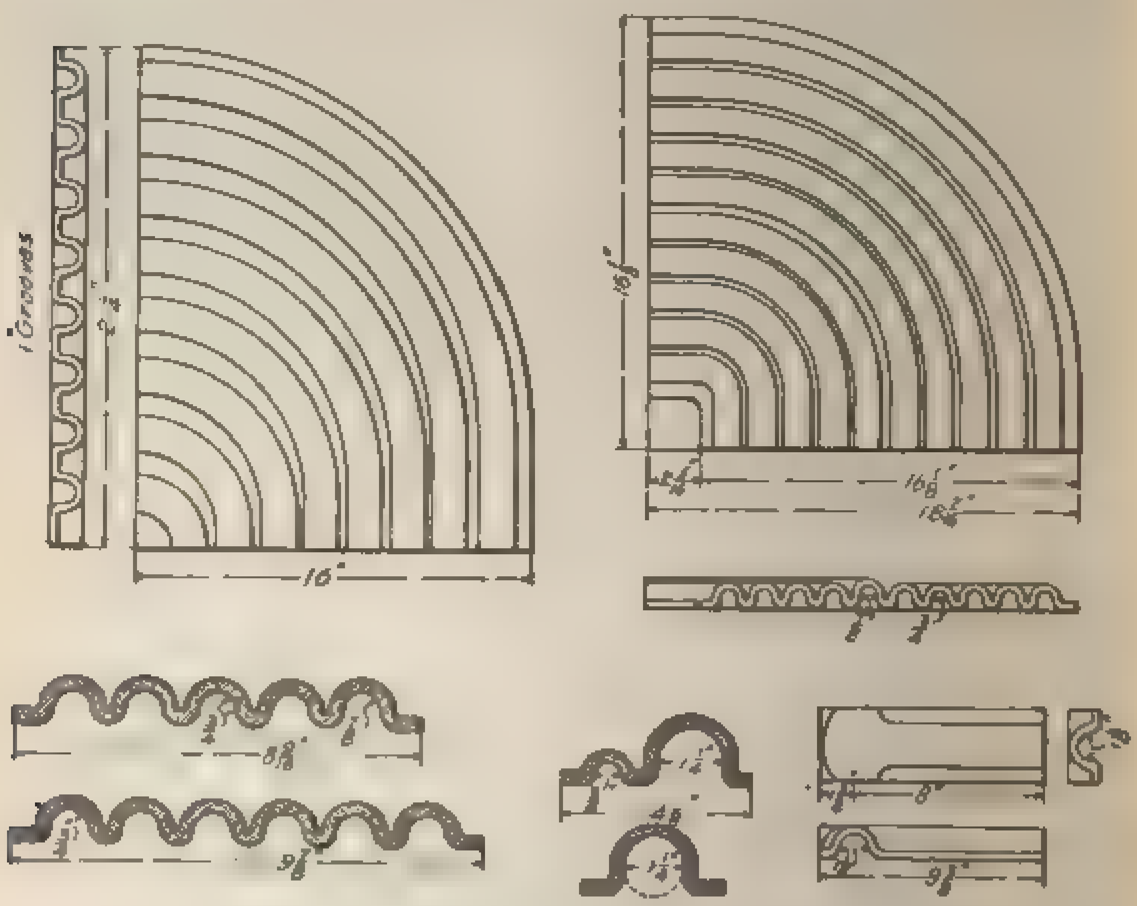

FIG. 27

to the maple sheathing was a ½-inch layer of *transite board*, another special insulation not affected by water. After the installation of the transite, all nails passing through it were tested for insulation to see that they touched no grounded part. The molded type of insulation is specially adapted to those equipments on which all main-motor wires can be kept under the floor, the area to be insulated being there more congested and limited than on equipments employing platform controllers.

**26.** The following abstracts from the rules of the National Board of Fire Underwriters emphasize the importance of taking every practicable precaution to minimize the fire risk when installing car wiring, and thereby incidentally minimize the chances of operating troubles.

On cars equipped with motors of over 75 horsepower each, the under side of the car body should be lined with at least $\frac{1}{8}$-inch approved insulation material or sheet iron or steel $\frac{1}{25}$ inch in thickness, extending 8 inches beyond all edges of motor openings, resistances, and other electrical apparatus not amply protected by the containing case. All conductors must be stranded and joints must be so spliced as to be both mechanically and electrically secure without solder, then soldered and covered with insulation equal to that on the conductor. All cut-outs and switches having exposed live metal parts are to be located in asbestos-lined cabinets. Cut-outs and switches not in iron boxes or in cabinets must be mounted on not less than $\frac{1}{4}$-inch fire-resisting insulating material, which must project at least $\frac{1}{2}$ inch beyond all sides of the cut-out or switch. A cut-out switch must be placed as near as practicable to the current collector so that the opening of the fuse in this cut-out will cut off all current from the car. All conduits where exposed to dampness must be water-tight. All junction and outlet boxes must be so installed as to be accessible. Joints in molding must be mitered to fit close, the whole material being firmly secured in place by screws or nails and treated inside and out with waterproof paint.

**27.** The current used in determining the size of trolley, motor, and resistance leads is taken as a percentage of the full-load current, as given in Table I.

Table I is to be used in conjunction with Table II, taken from the Underwriters' table of carrying capacity of rubber-covered wires.

Suppose that it is required to determine the size of trunk wire to be used with an equipment of four 50-horsepower motors. The total horsepower is 200, corresponding to a

current of 300 amperes at 500 volts. From Table I, the size of wire is to be based on 40 per cent. of the current. $.40 \times 300 = 120$ amperes. From Table II, the allowable size for 120 amperes is No. 0 B. & S., having a cross-section of 105,500 circular mils.

TABLE I

| Size of Each Motor Horsepower | Motor Leads Per Cent. | Trolley Leads Per Cent. | Resistance Leads Per Cent. |
|---|---|---|---|
| 75 or less | 50 | 40 | 15 |
| Over 75 | 45 | 35 | 15 |

TABLE II

| B. & S. Gauge | Amperes | Circular Mils |
|---|---|---|
| 8 | 33 | 16,510 |
| 6 | 46 | 26,250 |
| 5 | 54 | 33,100 |
| 4 | 65 | 41,740 |
| 3 | 76 | 52,630 |
| 2 | 90 | 66,370 |
| 1 | 107 | 83,690 |
| 0 | 127 | 105,500 |
| 00 | 150 | 133,100 |
| 000 | 177 | 167,800 |
| 0000 | 210 | 211,600 |

The size of *motor leads*, by which is meant the size of wire running from each motor terminal, is obtained as follows: The full-load current of each motor is 75 amperes; from Table I, 50 per cent. of 75 amperes is 37½ amperes; from Table II, the wire to be used is No. 6 B. & S.

# ELECTRIC-CAR-HEATING APPLIANCES

## ELECTRIC HEATERS AND CONNECTIONS

**28.** All **electric heaters** are made on the same principle—that of enclosing a high-resistance wire in a case designed to keep the feet and clothing of passengers out of range of the hot wire. According to the size of car and the make of heater, four, six, eight, ten, twelve, or even twenty heaters are required per car. For a given amount of heat required, the smaller the heater and the more of them that are used, the more evenly will the heat be distributed through the car, but the more places will thus be created where trouble is liable to arise.

As regards efficiency, heaters of all makes are about the same. To keep a 20-foot closed car comfortable during average weather in the vicinity of New York requires a current of about 10 amperes at 500 volts; this is between 6 and 7 horsepower per car. Therefore, it costs considerable to heat a car by electricity, and when the heaters are in use there is quite a large additional load thrown on the station. On the other hand, electric heaters occupy no passenger space, they distribute the heat more uniformly than stoves, they are cleaner, and they allow the heat to be more easily regulated. For these reasons the electric heaters are extensively used, even though they are more expensive to operate than coal stoves. They are nearly always installed in such a manner that at least three degrees of heat can be obtained by operating a **heater switch,** which changes the connections of the heaters.

The number of makes and styles of heaters is large, and it would be out of the question to treat all of them here. One or two typical examples will be described, however, in order to illustrate the method of connecting, which is practically the same for all makes.

Fig. 28

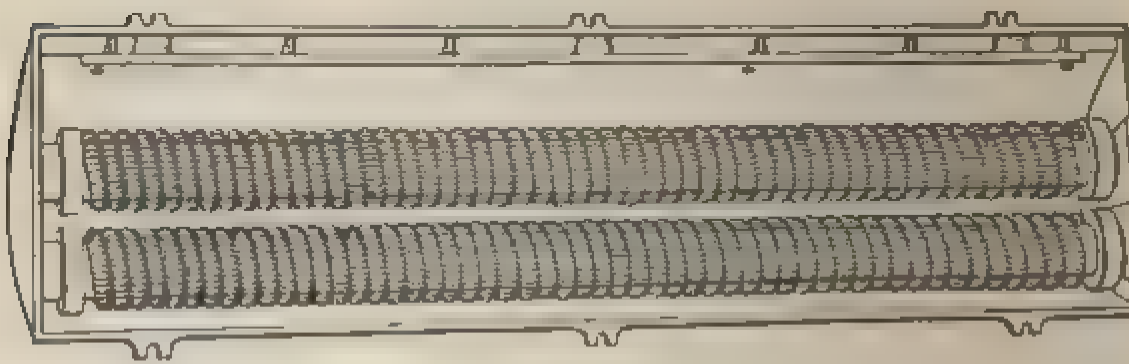

Fig. 29

Fig. 30

Fig. 31

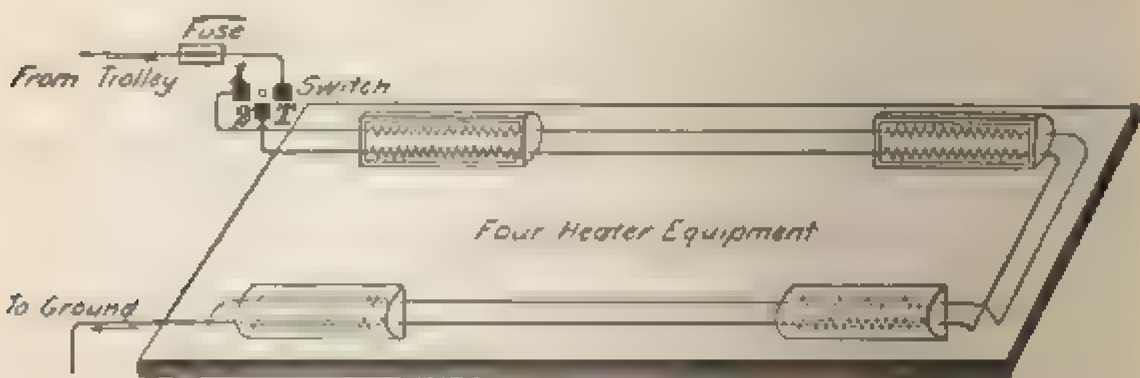


Fig. 32

### TYPE OF PANEL HEATER

**29.** Fig. 28 shows the coil used in a standard type of car heater made by the Consolidated Car Heating Company and constructed as follows: On a stout rod are strung porcelain tubes that run the full length of the heater. These pieces have a spiral groove made continuous the full length of the core by the manner in which the porcelain-tube sections are placed on the rod. The heater coil is placed in this groove and a large amount of wire is thus placed in a limited space in a manner that admits of free circulation of air. The terminal wires that run out of the case at each end through porcelain bushings are attached to the ends of the coils by twisted and soldered joints and are well secured without the aid of binding posts. In each heater are two coils, like that shown in Fig. 28, placed one above the other, as indicated in Fig. 29, which represents a heater with the front plate removed to show the two coils in place. The type illustrated is for a side-seated car, and is intended to be set into a rectangular hole cut in the seat panel. Similar but shorter coils are adapted to cases of cylindrical form to be installed under cross-seats.

Fig. 30 shows the style of coil and the method of mounting it in the cylindrical type of heater made by the Gold Car Heating Company. Fig. 31 shows the Gold cylindrical heater complete.

### HEATER-WIRING DIAGRAM

**30.** All electric-heater systems employ practically the same method of connecting the heaters and regulating the heat. Each heater has two independent coils, one of higher resistance than the other. Fig. 32 shows the heater wiring for a set of four Consolidated heaters controlled by the heater switch illustrated in Fig. 33. All top sections of the heaters are connected in series and all bottom sections are similarly connected. The negative ends of both sections of the last heater are grounded, on a ground return system, or permanently connected to the negative conductor of a

metallic-return system. The positive ends of the two series of sections are so connected to the heater switch that on the first position of the handle all top sections are in series across the line; on the second position, the top sections

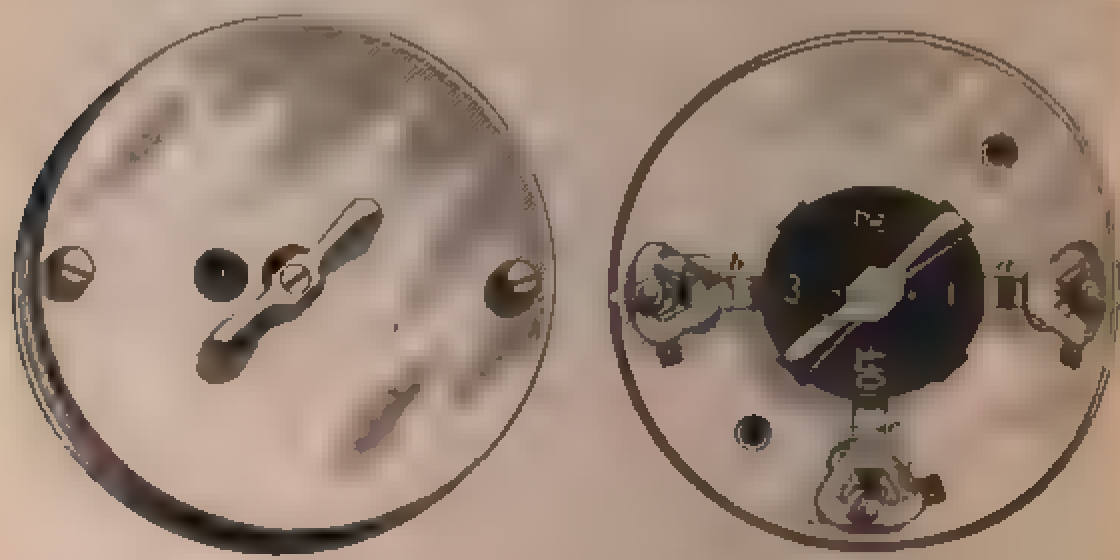

FIG. 33

are cut out but the bottom sections are in series; on the third position, the top and bottom sections are in parallel with each other, thus giving the greatest degree of heat obtainable with the given heaters. On the off-position of the heater switch all current is cut off.

---

## OTHER SYSTEMS OF HEATING

**31.** Other devices than electric heaters are used for heating electric cars. Among them are the stove, hot-water system, and a system whereby the heat generated in the starting coil of the car is utilized. The main objection to electric heaters is the cost of the energy required by them, being more than one-third of that required to propel the car. The objections to **stoves** are the dirt that they make and the space occupied.

In the **hot-water system** of heating, the water flows through a closed circuit of heat piping including a pipe spiral contained in a firebox at one end or at the center of the car. The main objection to the hot-water system is the lial

freezing unless the cars when not in use are kept fired or are laid up in a heated car house.

The **starting-coil heating system** is a feature of the combination traction brake and heat system of the Westinghouse Traction Brake Company. Resistance coils inside the car absorb the waste energy incident to starting and to generation of current by the motors when utilizing the traction brake. In warm weather such an arrangement would not be desirable, so that provision is made for then using the customary starting coil located under the car.

# ELECTRIC-CAR LIGHTING

## INCANDESCENT LIGHTING CIRCUITS

### REMARKS

**32.** The **incandescent lighting circuits** on a car include the interior incandescent lamps, the rear platform lights of a surface trolley car, and possibly a hood or dash headlight, together with the facilities for changing over one or more lamps when the operating end of the car is changed. On cars to be made up into trains, there must be facilities for lighting both platforms on all but the forward car, which will probably also require signal lights, or markers, on the bonnet in addition to the headlight on the hood; and there must be change-over switches with which to change the headlight, markers, and platform lights to suit local conditions. In addition to lighting the car, the lamp circuit, when in good condition, is an indication as to whether the line is alive or not and as to the condition of the voltage.

### EXAMPLES OF INCANDESCENT LIGHTING CIRCUITS

**33.** Fig. 34 shows a form of change-over switch that accomplishes the same result as the plug shown in Fig. 35. Both are used to cut one lamp out of circuit and cut another

in its place, as indicated in Fig. 36, which shows about the simplest arrangement of lamps for a car that must operate from both ends and always have a headlight and a rear-platform light. With the two plugs or switches in the full-line positions of the diagram, a headlight *H L* burns on both ends; with both plugs or switches in the dotted-line positions, a platform light *P L* burns on both ends. To get a headlight on one end and a platform light on the other, one switch or plug must be in the full-line position and the other in the dotted-line position.

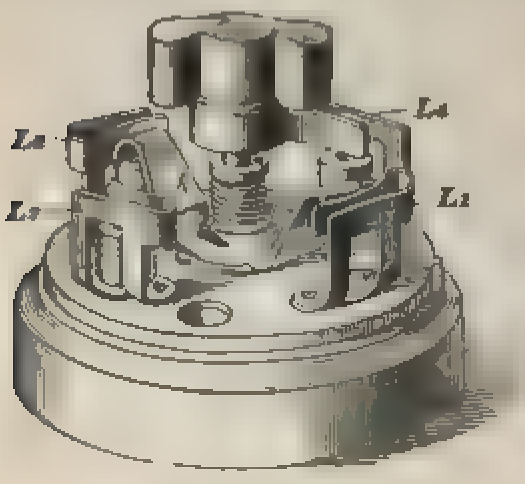

FIG. 34

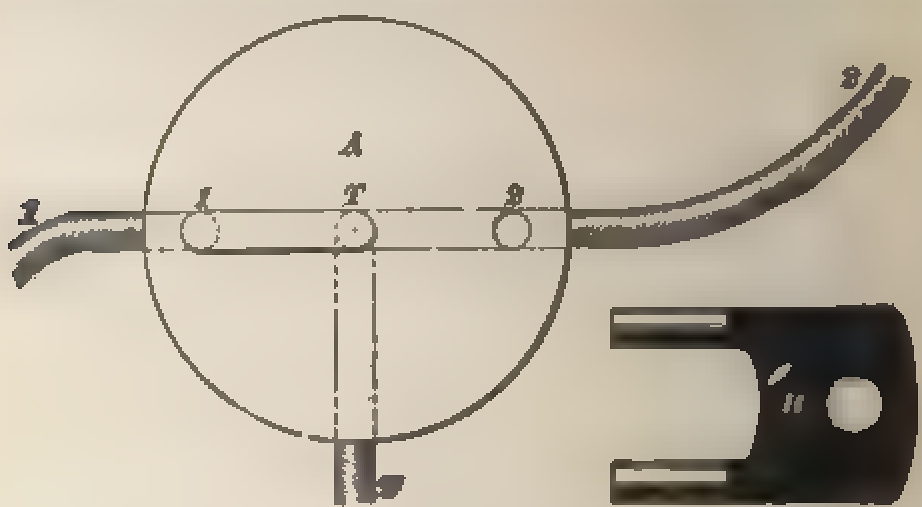

FIG. 35

**34.** Fig. 37 shows a plan of wiring for an elevated car employing both headlights and markers; the markers are

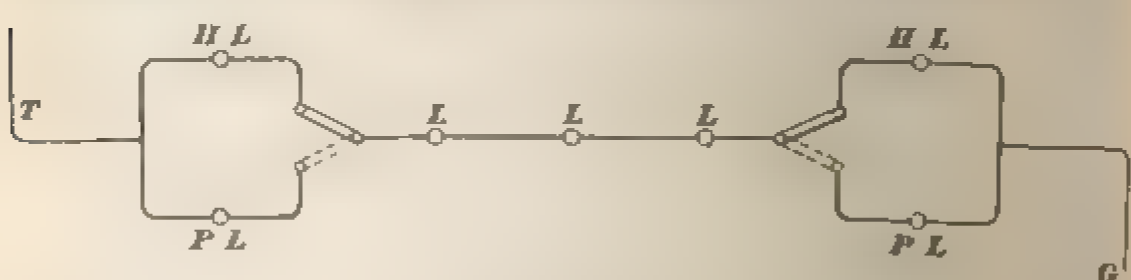

FIG. 36

intended to indicate the destination of a train. *M, M* and *H L* are the markers and headlight on one end of the

car and $M'$, $M'$ and $H' L'$ those on the other end. $L$, $L$, the two lamps inside the car, light whenever the signal lights on either end of the car are in use.

**35.** Fig. 38 is the lamp-circuit wiring for an interchangeable dash light wired in a five-lamp circuit; the headlight, of

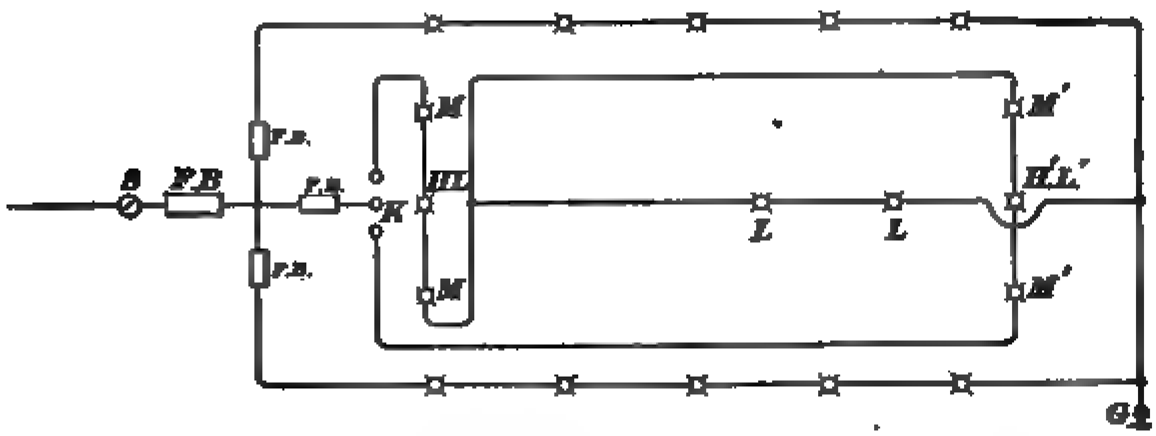


FIG. 37

course, has a lamp 7 of its own, and according as the headlight is on one end of the car or the other, lamps $L_1$ or $L_5$ are cut out and replaced by 7. In this figure, the headlight is in place on the right-hand end of the car and car lamp $L_5$

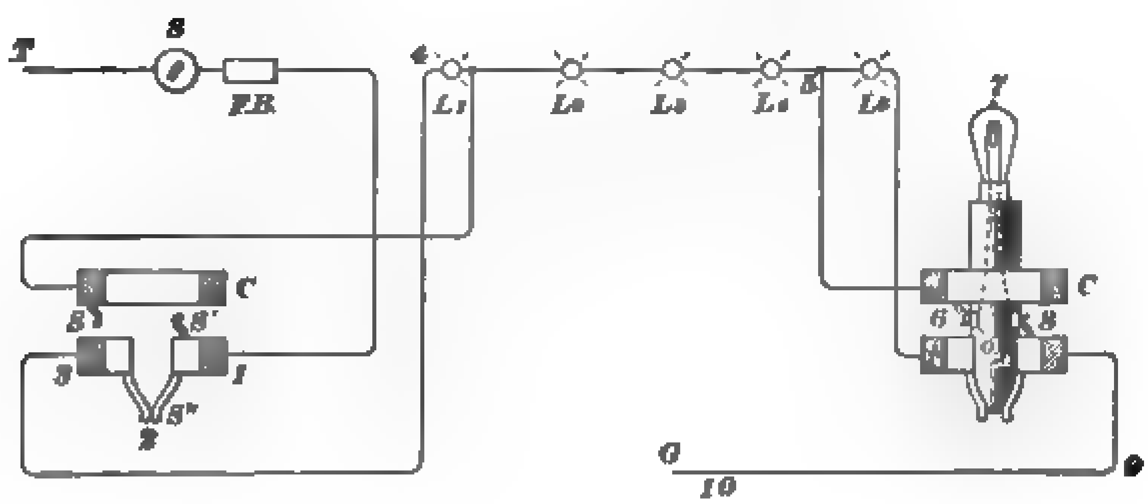


FIG. 38

is cut out. The path of the current is $T$–$S$–$FB$–1–2–3–4–$L_1$–$L_2$–$L_3$–$L_4$–5–6–7–8–9–10–$G$. In the side of the tongue that slides into the socket are two contact plates, shown at $o$ and $x$, to which are connected the two wires from the posts of lamp 7. At $S$, $S'$ are shown the springs that make contact with these two plates when the tongue is forced into the

socket. Springs $S''$ make a path for the current when the headlight on that end of the car is not in place. As soon as the tongue is dropped into the socket, its end forces the two springs apart and the current flows through the headlight.

## ARC HEADLIGHT CIRCUIT

**36.** In suburban service, where cars run at high speed across numerous grade crossings, powerful **arc headlights** are used to illuminate the right of way for a considerable distance ahead of the car. In city work, the strong light projected by an arc lamp is undesirable.

Fig. 39 is a general, and Fig. 40 a sectional, view of the Crouse-Hinds combination arc headlight, which is provided

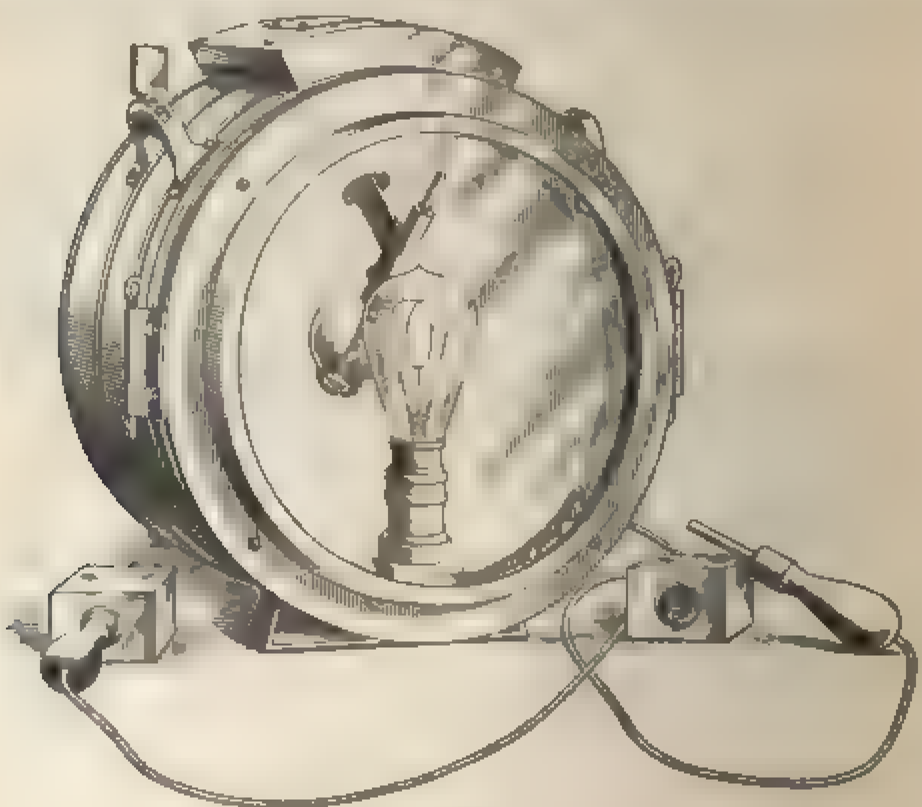

FIG. 39

with an incandescent light attached inside the door so that for city work the smaller light can be used. The arc-light carbons are inclined at an angle of 45° with the perpendicular, to present a large area of crater to the center of the reflector and to a certain extent overcome the dark spot usually present when vertical carbons are used. The initial drawing of the

arc or its reestablishment after running over a line breaker or otherwise interrupting the current, and the feeding of the carbon are automatically controlled by a coil in series with

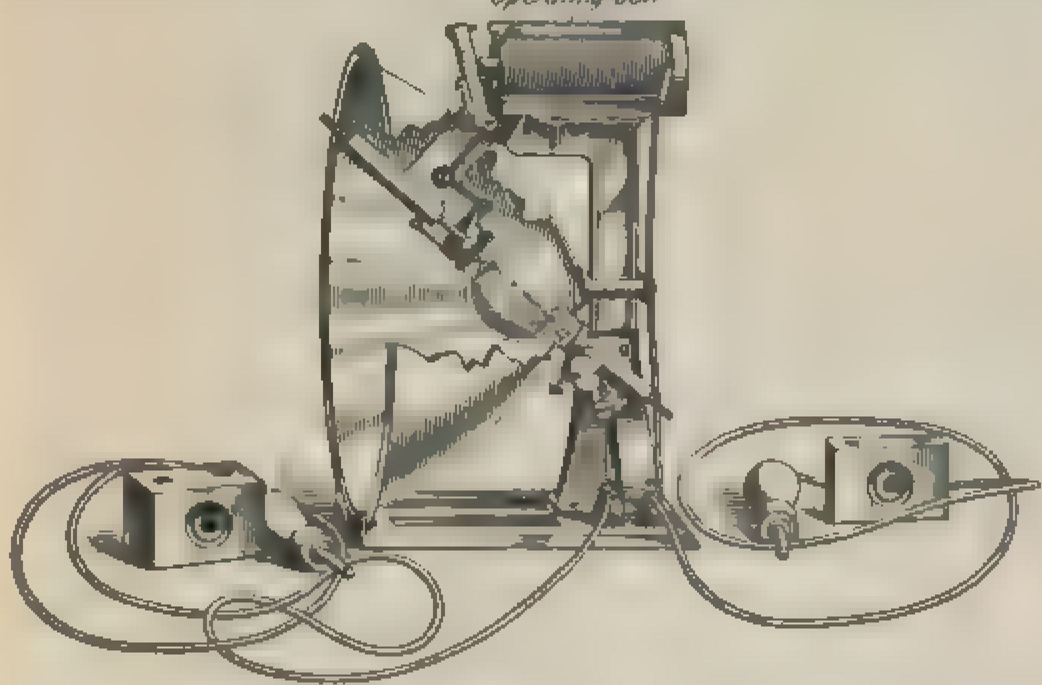


FIG. 40

the arc. The resistance used in series with the arc light is such as to admit a current of $3\frac{1}{2}$ amperes at 550 volts, the drop across the arc then being about 75 volts. Both the

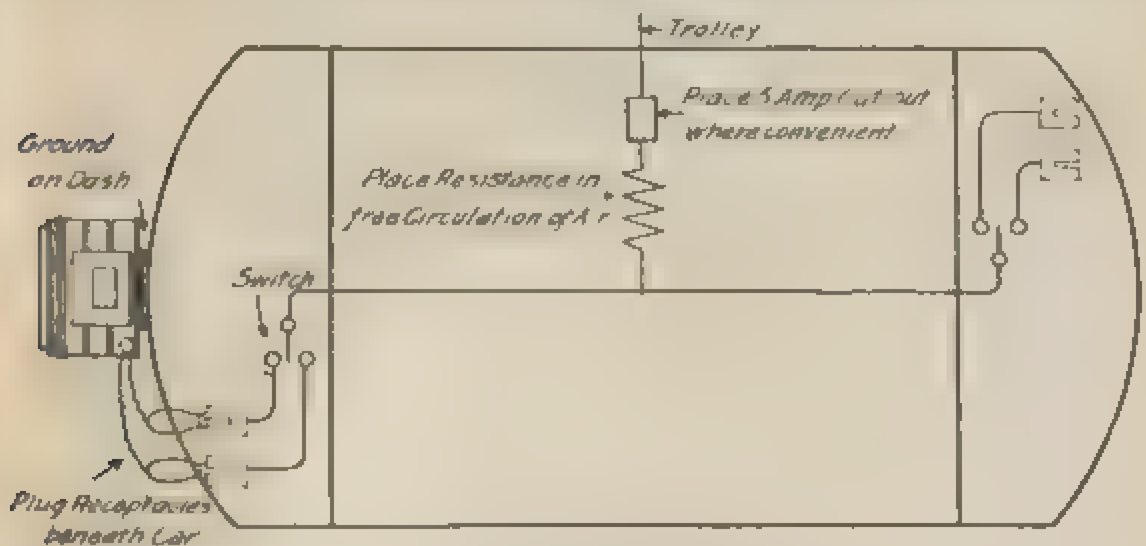


FIG. 41

incandescent attachment, supported on the door, and the arc-lamp circuits have plugs and receptacles of their own, and in order to obviate the necessity of pulling the plug of the lamp

circuit that it is not desired to use, both receptacles are connected to a two-way switch, the position of which determines which circuit shall be supplied with current. When the headlight is changed from one end of the car to the other

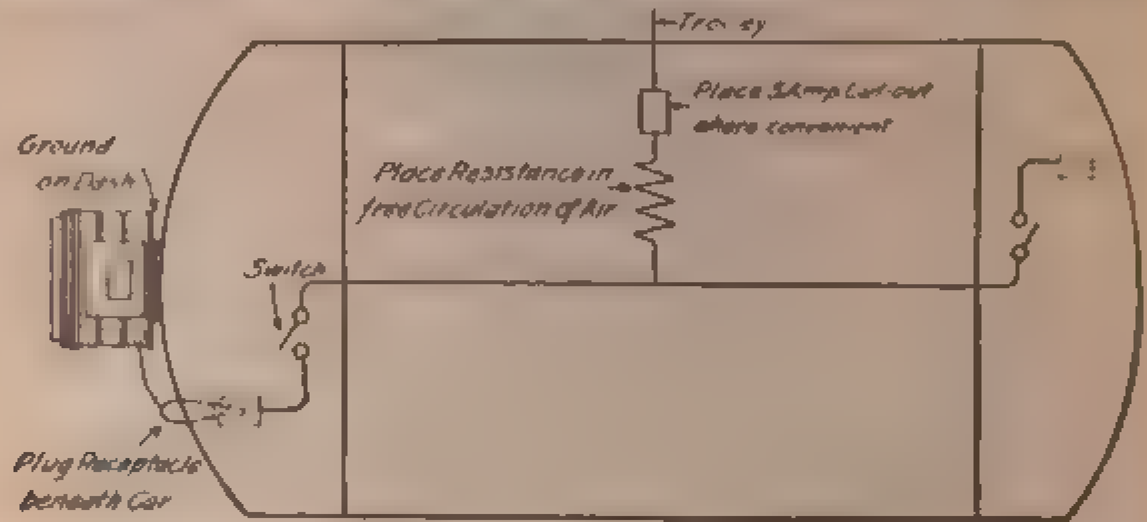


FIG. 42

both plugs must be removed from the receptacles. Fig. 41 is a diagram of connections when both lamps are installed, and Fig. 42, the connections for the arc lamp only, the incandescent attachment being omitted.

## TRACK SIGNALS

**37.** On single-track electric roads, turnouts or sidings are provided to enable a fast car to pass a local and oppositely

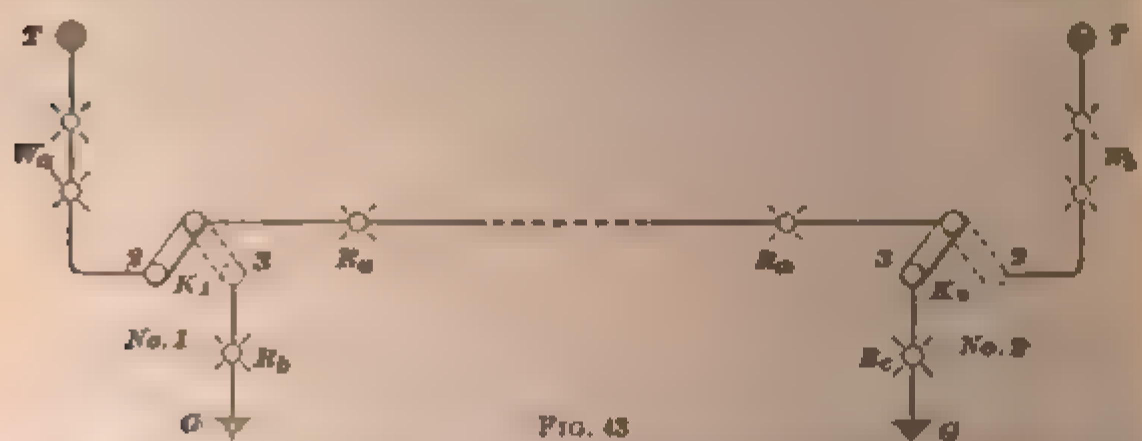


FIG. 43

bound cars to pass each other. The stretches of single track between sidings must be protected by signal systems, so that oppositely bound cars may not meet in collision or

fast car run into a slow one. In some cases, elaborate automatic signals are installed, but usually the signal system is manual in operation, consisting of a signal-lamp box at each end of the stretch of single track connecting two turnouts. The signal generally takes the form of a red light to block a car, and a white light or no light to show a clear track. Fig. 43 illustrates the connections of a simple signal system.

**38. Simple Signal System.**—In Fig. 43, $K_1$ and $K_2$ are two-way switches, one of which is located at each end of the stretch of single track to be protected. The switch tongues are connected by No. 10 iron wire strung on the line poles and including two 16-candlepower incandescent lamps $R_a$, $R_a$ provided with red globes. Each switch has a trolley contact *2* and a ground contact *3* including a red lamp ($R_b$ and $R_c$). Each trolley contact includes two white lamps $W_a$, $W_b$. When the two switch tongues are in their full-line positions, white lamps $W_a$ and red lamp $R_a$ burn in the No. *1* signal box, while red lamps $R_a$ and $R_c$ burn in the No. *2* signal box. With the two switch tongues in their dotted-line positions, however, red lamps $R_a$ and $R_b$ burn in the No. *1* box and white lamps $W_b$ and red lamp $R_a$ in the No. *2* box. If both switch tongues rest on contacts of the same polarity, no lamps can burn.

**39.** Assume that a crew approaching the No. *1* box finds all lights out; under this condition either the system is out of order or both switch tongues are on ground or trolley. The conductor throws the handle to the opposite side, and if the lamps light it shows that they were extinguished by the conductor of another car leaving the block. If the lamps light just before he is able to throw the switch, it means that the conductor on a car entering the other end of the block has thrown his switch and the first car must wait until the second car comes through and clears the block. The conductor before entering the block now throws the switch to the other side to protect himself and throws the switch in the signal box at the other end of the block, when passing out, clear the block for the next car.

# BRAKES

## INTRODUCTION

**40.** The most important part of any car equipment is the **brakes**, and they are closely involved in the financial success of a road. If cars are equipped with modern motive appliances but provided with a poor system of brakes, or if a good system of brakes is grossly neglected, loss due to accidents will be sure to result. Conditions governing the manner of applying brakes effectively vary widely, and the degree to which brakes in good order can be applied depends on the friction between wheel and rail and on that between wheel and shoe. When a brake is applied, the friction between wheel and rail tends to keep the wheel turning, while that between the shoe and wheel tends to stop the latter. The frictional effect tending to stop the wheel or keep it turning depends on the nature of the surfaces in contact and on the force with which the surfaces are pressed together.

The pressure tending to stop the wheel is proportional to the force exerted by the brake shoe; the pressure tending to keep the wheel rolling is proportional to the weight resting on the wheel. The permissible pressure to be applied to a shoe without locking a given wheel will vary with shoes of different material; for example, a shoe pressure that would not lock a wheel braked by an iron shoe might lock it if a wooden shoe were substituted, because the coefficient of friction of wood and iron surfaces is greater than that for iron and iron. In practice, where cast-iron shoes are used to brake cast-iron or cast-steel wheels, long experience has established the rule of making the shoe pressure applied to a wheel 90 per cent. of the weight resting on the rail under the wheel; and foundation brake riggings are designed accordingly. In electric-railway service, however, and

especially in high-speed service employing heavy motors, the pressure applied to the shoe is sometimes made 10 per cent. greater than the weight resting on the rail under the shoe. This increase in the percentage of braking pressure is rendered practicable by the inertia of the heavy rotating armatures, which tend to keep themselves and the geared wheels turning after braking pressure is applied, thereby making the effective weight tending to keep the wheel rolling greater than the actual weight resting on the rail. When all axles do not carry motors, care must be taken to design the foundation rigging so that the extra shoe pressure permitted by armature inertia will be applied only to those wheels that are geared to armatures.

Irrespective of the system of brakes used, the degree to which brakes can be effectively applied and the manner of applying them depend on the condition of the rail. An application that will stop a car satisfactorily on a clean rail may cause the wheels to lock and slide on a slippery one, the slippery condition seeming to affect the rail-wheel friction much more than it does the shoe friction. Braking conditions on a slippery rail are improved by applying sand to one rail, as is usually done, and the improvement is increased 100 per cent. by sanding both rails, as is seldom done, except in steam practice.

On surface trolley cars, hand-brakes are generally used; they can be designed to stop the heaviest cars at high speeds, but in doing so the travel of the brake-lever arms becomes so great that considerable time is required to take it up and effect a stop. On high-speed suburban cars, on elevated cars, and for other heavy traffic, air brakes are used. On single cars or on two-car trains, straight air brakes are used, while on longer trains automatic brakes are depended on. All forms of power-brake equipment, however, are supplemented by hand-brakes, which are retained as a factor of safety in case the power brake should fail or should it be necessary to brake a car cut off from the source of power.

## HAND-BRAKES

### SINGLE TRUCK

**41.** Fig. 44 shows a common form of **single-truck brake rigging,** most of the parts of which are designated in the figure. Brake beams *B*, *B* are supported on the ends and slide in cast-iron brake-beam castings fixed to the side frames of the truck. In Fig. 45, *A* is the slide casting; *B*, the beam; and *F*, the truck member that supports the casting. Equalizer rods *r*, *r*, Fig. 44, connect to equalizer bars *E*, *E* and each equalizer rod ends in a jaw *J*, to which the equalizer bars are rigidly connected, but in which the brake beams move freely, as shown in Fig. 46, where *R* is the rod; *J*, the brake jaw; *B*, the beam; and *E*, the equalizer bar. In Fig. 44, links *H*, *H* are connected to the brake levers *L*, *L* and equalizer bars by means of pins. Links *I*, *I* connect the brake lever and brake beams. *F* is a pin around which *L* and *H* can move, and $F_1$ is a pin common to *L* and *B*. In the diagram, the brakes are shown off and the shoes have been pulled away from the wheels by the release springs *K*, *K*. One end of each spring

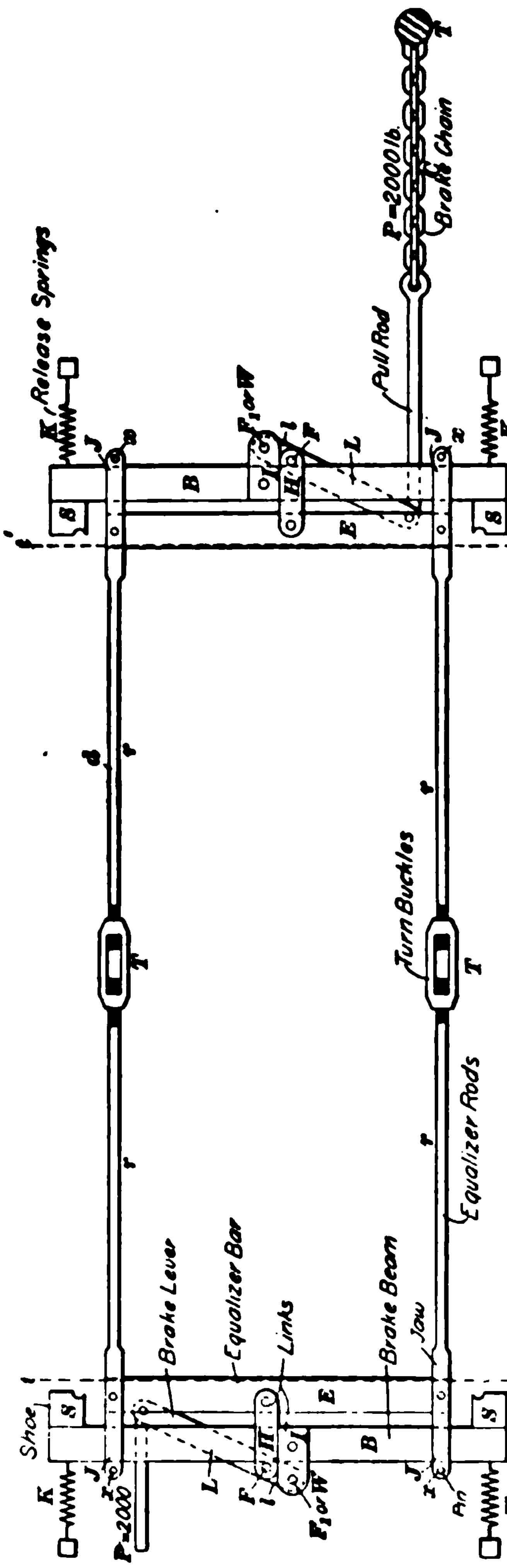


FIG. 44

is fixed to a lug on the car truck and the other end to the brake beam or shoe head. Brake slides wear rapidly and give trouble in winter by getting stopped up with frozen mud; the main objection is that the harder the brakes are set, the harder the brake beams press against the brake slide castings, with the result that the harder the brakes are set, the harder it is to set them. The operation of the brake will be apparent from an examination of Fig. 46. The force exerted on the pull rod $P$, Fig. 44, draws the brake beams $B$, $B$ together, and thus presses the shoes $S$, $S$ against the wheels.

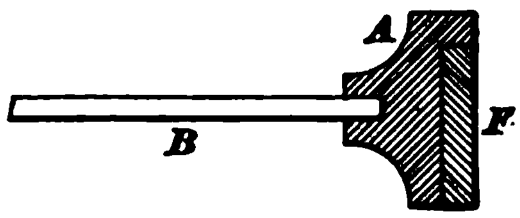

FIG. 45

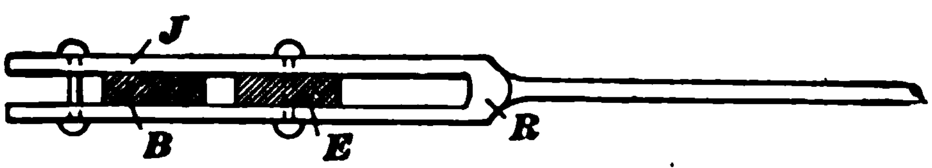

FIG. 46

**42.** The main objections to existing single-truck riggings are that the release springs do not always effectively keep the brake shoes off the wheels, and the nature of the lever construction is such that the brakes apply harder on the rear end than on the forward end. A glance at the brake rigging of almost any single truck will show that the shoes on one end are an inch or more away from their wheels, while those on the other end cling to their wheels. The brake levers are all released, but the release springs on one end being stronger than on the other pull the weaker springs out and force their shoes to the wheels with pressure depending on the difference in strength of the opposing release springs. Fig. 47 illustrates diagrammatically the leverage of one end of the single-truck rigging of Fig. 44. Lever $PFW$ is 36 inches long and $S_2$ is the rear brake beam connected to $PFW$ at $F$, through rod $FS_2$; $S_1$ is the front brake beam. Supposing the shoes on beam $S_2$ to be against their wheels,

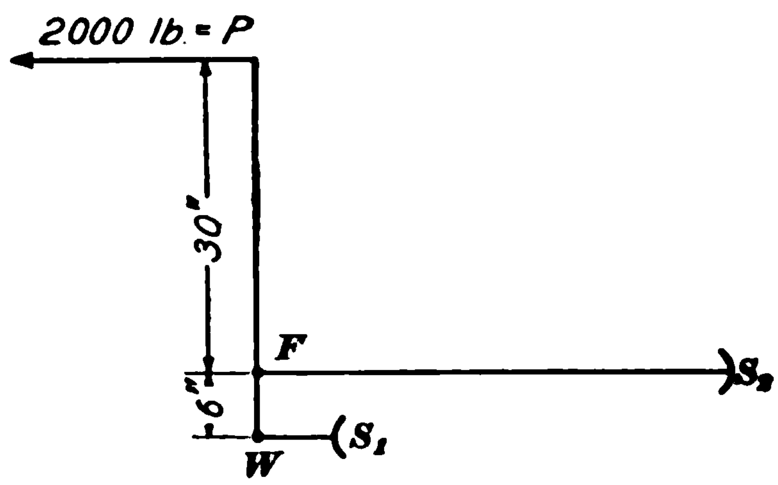

FIG. 47

a pull of 2,000 pounds at $P$, in the direction of the arrow, will force beam $S_1$ against its wheels with a pressure of $\frac{30}{6} \times 2{,}000 = 10{,}000$ pounds. Supposing the shoes on beam $S_1$ to be against their wheels, a pull of 2,000 pounds at $P$ will pull beam $S_2$ to its wheels with a force of $\frac{36}{6} \times 2{,}000 = 12{,}000$ pounds, a difference of 2,000 pounds, because beam $S_1$ is applied by a lever having its fulcrum between the applied force and the delivered force, whereas beam $S_2$ is operated by a lever having the delivered force between the fulcrum and the applied force.

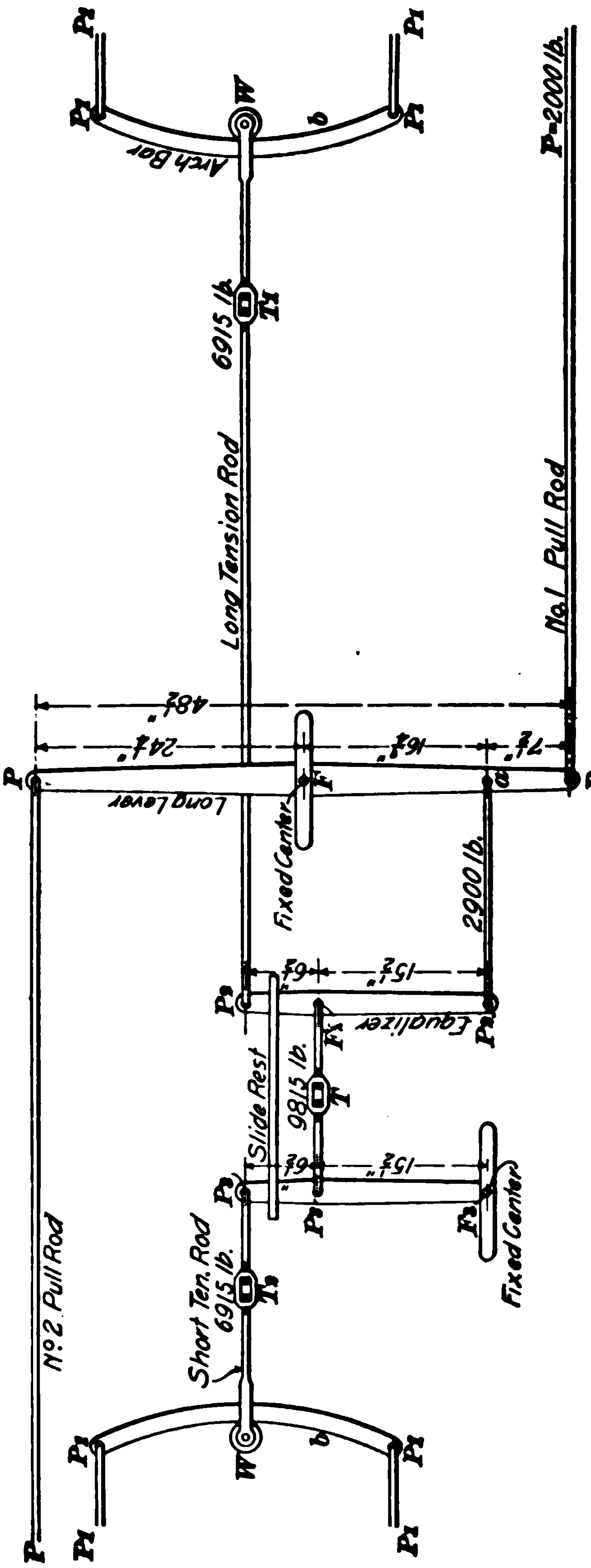


Fig. 48

## DOUBLE-TRUCK BRAKES

**43.** Fig. 48 shows a type of **double-truck rigging** much used. The tendency to apply the rear brakes harder than the forward ones exists on double-truck riggings, and is overcome by the use of an extra equalizing

lever that cannot well be applied to single trucks. In Fig. 48, fulcrum $F$ and fulcrum $F_3$ of the equalizing lever are fixed to the car body. Levers $P_2F_2P_2$ and $P_3P_3F_3$ are supported by a strap hanger that permits horizontal sliding motion and are connected by turnbuckle rod $F_2P_3$. The rigging is indicated in the position of best leverage, the brake being set. Assume a pull of 2,000 pounds to be exerted on lower pull rod $P$ causing the lower end of lever $PFP$ (of which the long arm $PF$ is $24\frac{1}{4}$ inches and the short arm, $16\frac{3}{4}$ inches) to move to the right and thereby exert a pull on rod $a\,P_2$. The pull on $a\,P_2$ is $\frac{24\frac{1}{4}}{16\frac{3}{4}} \times 2{,}000 = 2{,}900$ pounds. As rod $a\,P_2$ connects to lever $P_2F_2P_2$, 2,900 pounds is the pull applied to this lever, of which the long arm is $15\frac{1}{2}$ inches and the short arm $6\frac{1}{2}$ inches, the fulcrum being at $F_2$ and the power being applied to the long arm. Accordingly, the pull on tension rod $P_2W$ is $\frac{15.5}{6.5} \times 2{,}900 = 6{,}915$ pounds. The pull on turnbuckle $F_2P_3$ is $6{,}915 + 2{,}900 = 9{,}815$ pounds, which if applied directly to the short tension rod $P_3W$ leading to the arch bar of the rear truck would apply excessive braking pressure. To avoid such a condition, equalizing lever $P_3P_3F_3$ is introduced, the effect of which is to make the pull on short tension rod $P_3W$, 6,915 pounds, the same as on the long rod $P_2W$, thereby insuring that the braking pressure on both trucks shall be the same.

**44.** Rods $P_1$, $P_1$ connecting to the ends of the arch bars are the truck pull rods that apply the braking pressure to the truck levers. Fig. 49 shows half the truck rigging on a truck equipped with inside hung brakes. A pull to the left on rod $PP_1$ forces shoes $S_1$, $S_2$ against their respective wheels, rod $P_2P_3$ being subjected to compression.

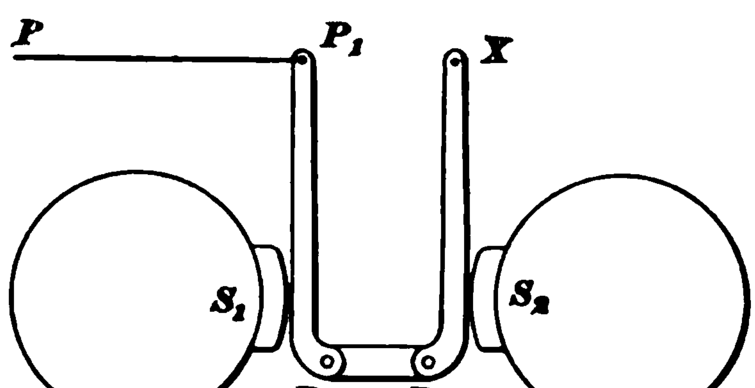

FIG. 49

## MAXIMUM-TRACTION BRAKES

**45.** The body rigging for **maximum-traction trucks** is the same as that for ordinary double trucks, but the truck rigging must be modified to divert the greater part of the braking pressure to the large wheels, the axle of which supports more than two-thirds of the weight of the motor. Fig. 50 illustrates half of the truck rigging used on the Peckham maximum-traction truck. Bent lever *A* has the truck pull rod connected to its upper end, while its lower end attaches to a push rod that operates the shoe *S* of the large wheel. Lever *A* has no stationary fulcrum, but is pivoted at *y* to lever *B*, which has a stationary fulcrum at *x*. The lower end of lever *B* connects to a push rod that applies the brake shoe *s* to the small wheel. A pull to the left on the pull rod turns lever *A* in a counter-clockwise direction on *y* as a center, thereby applying the large shoe *S* to the wheel; *z* then becomes a center around which lever *A* continues to turn, thereby causing lever *B* to turn in a clockwise direction on fixed center *x*, the lower end of *B* forcing small shoe *s* against its wheel. The movements of the large and small shoes have necessarily been considered consecutively, but as a matter of fact they take place simultaneously.

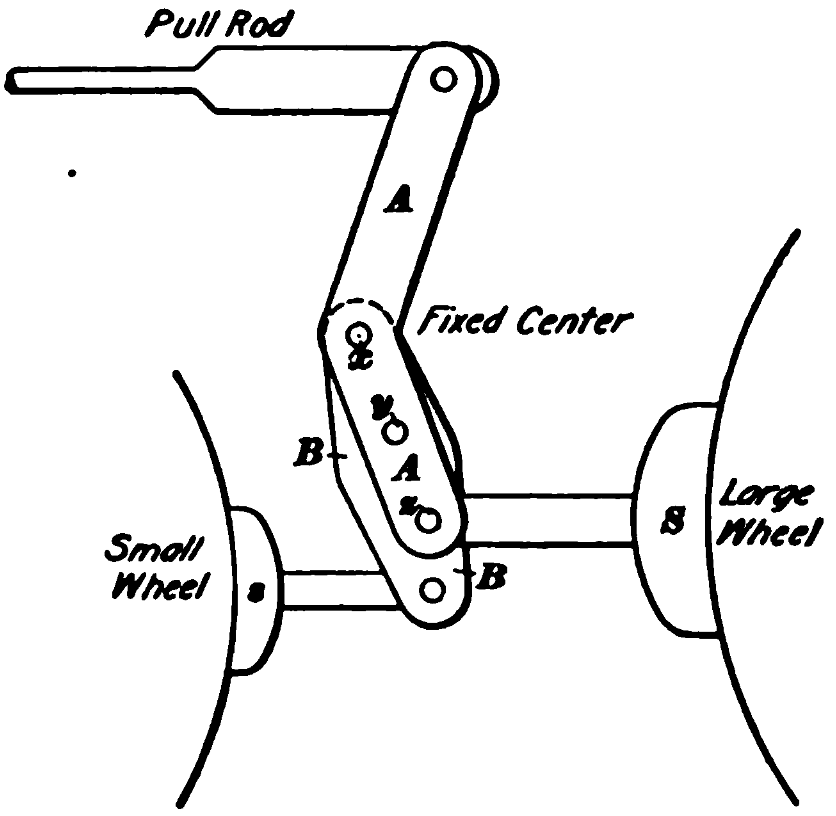


FIG. 50

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## STRAIGHT AIR BRAKES

**46. General Remarks.**—By a **straight air brake** is meant one operated by compressed air admitted from a storage reservoir directly to the brake cylinder without dependence on any automatic device. The straight air brake represents one method of securing a quick-acting powerful

brake, effective without manual exertion on the part of the operator, and free in design from excessive leverages. The air used for operating a straight air equipment may be compressed at stations located along the line and stored in a reservoir located on the car, in which case the system is known as the *storage air system;* or the compressed air may be obtained from an air compressor located on the car itself. In the latter case, the compressor may be driven from a car axle, in which case it is called an *axle-driven compressor*, or by an independent electric motor, in which case it is called an *independent-motor-driven compressor*.

**47. Principal Parts of Straight Air Equipment.** The principal parts of a straight air brake equipment that compresses its own air, are: the *air compressor*, usually driven by an electric motor; the *main reservoir*, or steel tank, into which the compressor stores the air to be used as required; the *automatic governor*, which starts and stops the compressor motor according as the main reservoir pressure is below or above a certain value; the *air gauge*, or *pressure gauge*, usually provided with a red hand, which indicates main-reservoir pressure, and a black hand, which indicates the pressure in the pipe line leading to the brake cylinder or cylinders; the *brake cylinder*, which carries a piston that operates the system of brake levers when communication is established between the reservoir and brake cylinder; the *engineer's valve*, by means of which the motorman lets air into the brake cylinder to apply the brake or discharges brake-cylinder air to atmosphere to release the brake; the *foundation rigging*, consisting of the various levers, rods, and carriers necessary to apply and support the brakes; the *pipe connections*, connecting the engineer's valves, brake cylinder, reservoir, compressor, governor, gauges, and coupling hose when the motor car is to haul a trailer or become part of a train.

**48.** On a storage air car equipment, the compressor and all parts connected with it are replaced by reservoirs carrying air stored in them at high pressure at compressor stations

located at termini and at intermediate points, if necessary. A *service reservoir* carrying the air at the pressure at which it is admitted to the brake cylinder, is connected to the high-pressure storage reservoirs through a reducing valve. The equipment has the usual foundation rigging, brake cylinder, gauges, and engineer's valves, and the method of operation is the same as that of a compressor equipment.

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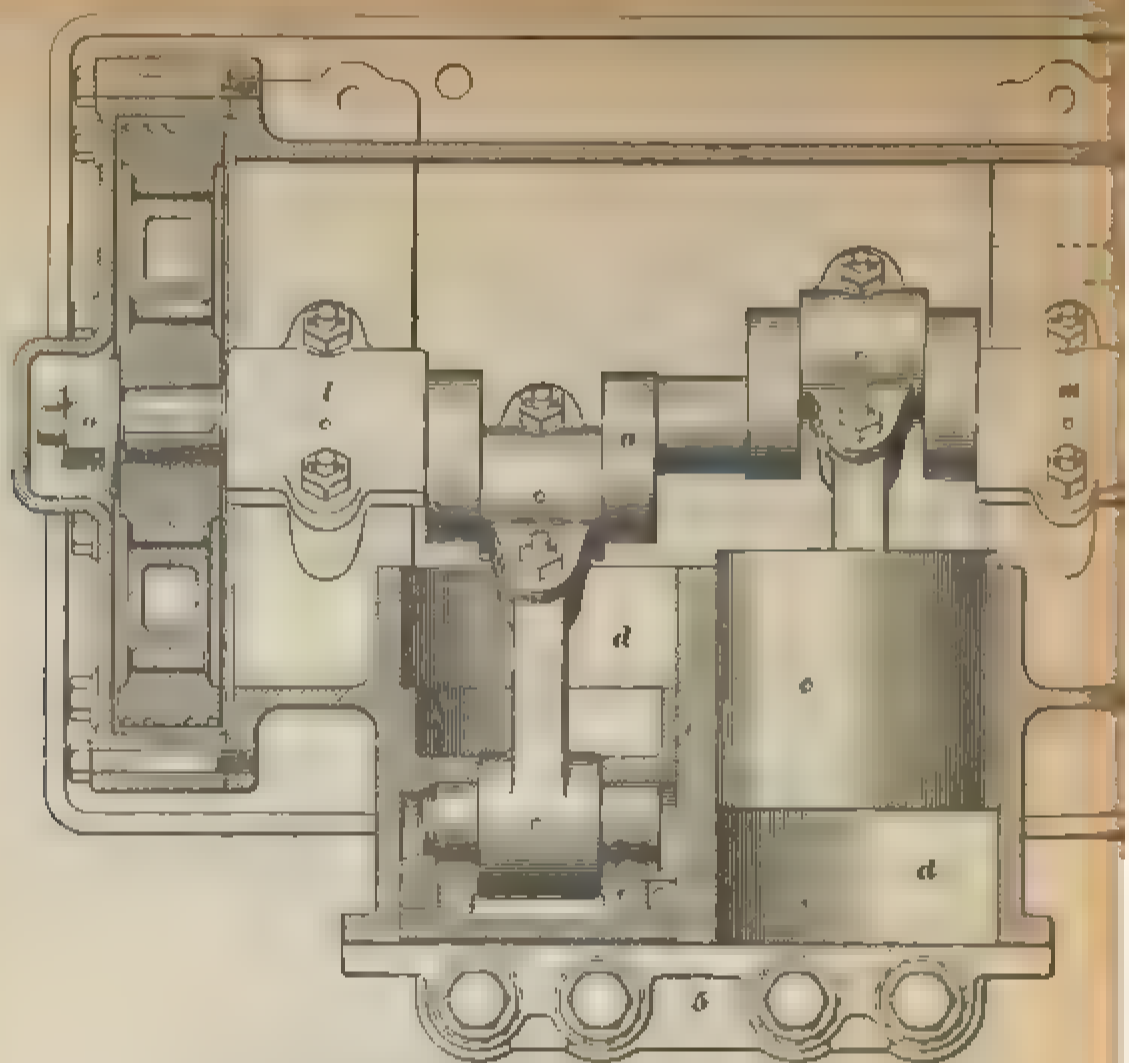
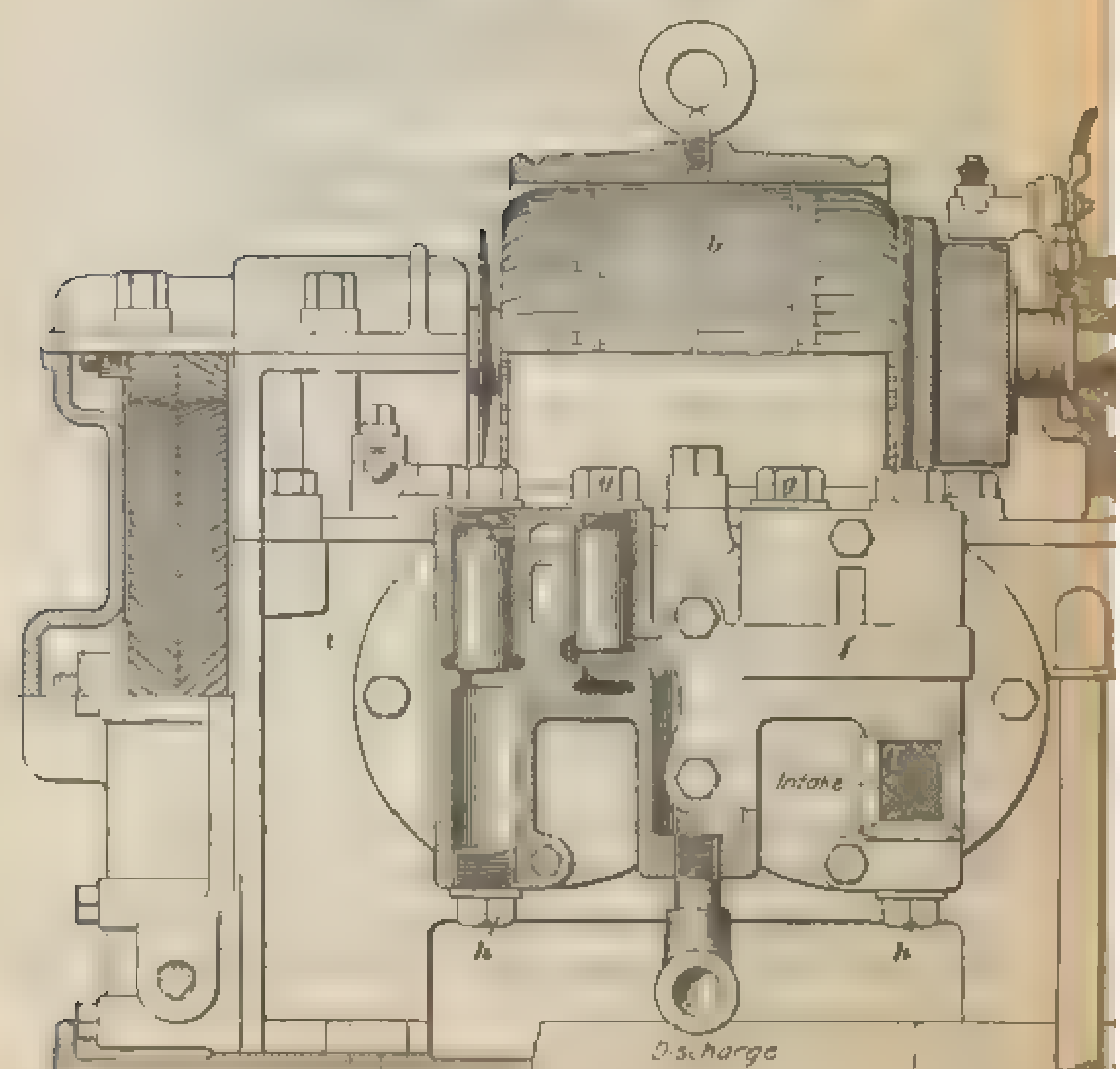
### EQUIPMENT WITH INDEPENDENT-MOTOR-DRIVEN COMPRESSOR

**49. The Compressor.**—Fig. 51 is a perspective view of the Christensen compressor with the top half of the motor frame and the two bearing caps removed in order to take out an armature. Fig. 52 (*a*) is a horizontal section through the pump casing; Fig. 52 (*b*), a partial vertical section showing the valve construction; and Fig. 52 (*c*), a section at right angles to the crank-shaft. The rotation of crank-shaft *a*, geared at one end to the shaft of armature *b*, oscillates pistons *c* in cylinders *d*. The pistons connect at opposite ends of a crank-shaft diameter, thereby minimizing vibration. The two cylinders with valves at but one end, constitute a double-cylinder single-acting pump. The gear-case and the crank-shaft chamber are kept partially filled with oil poured in through elbow *e*, which also gauges the level of the oil. Cylinder head *f* contains all valves, and its removal exposes the ends of the pistons and cylinders. The air inlets are protected by strainers that exclude dust from the suction valves. All valves are interchangeable, excepting in so far as wear may affect them, and can be withdrawn by removing caps *g*. To clean the valve chambers, plugs *h* must be taken out. To remove an armature, disconnect and lift off the top field frame *k* and remove caps *l* and *m*. To change a gear, draw off the oil and remove nut *o* and the gear-case.

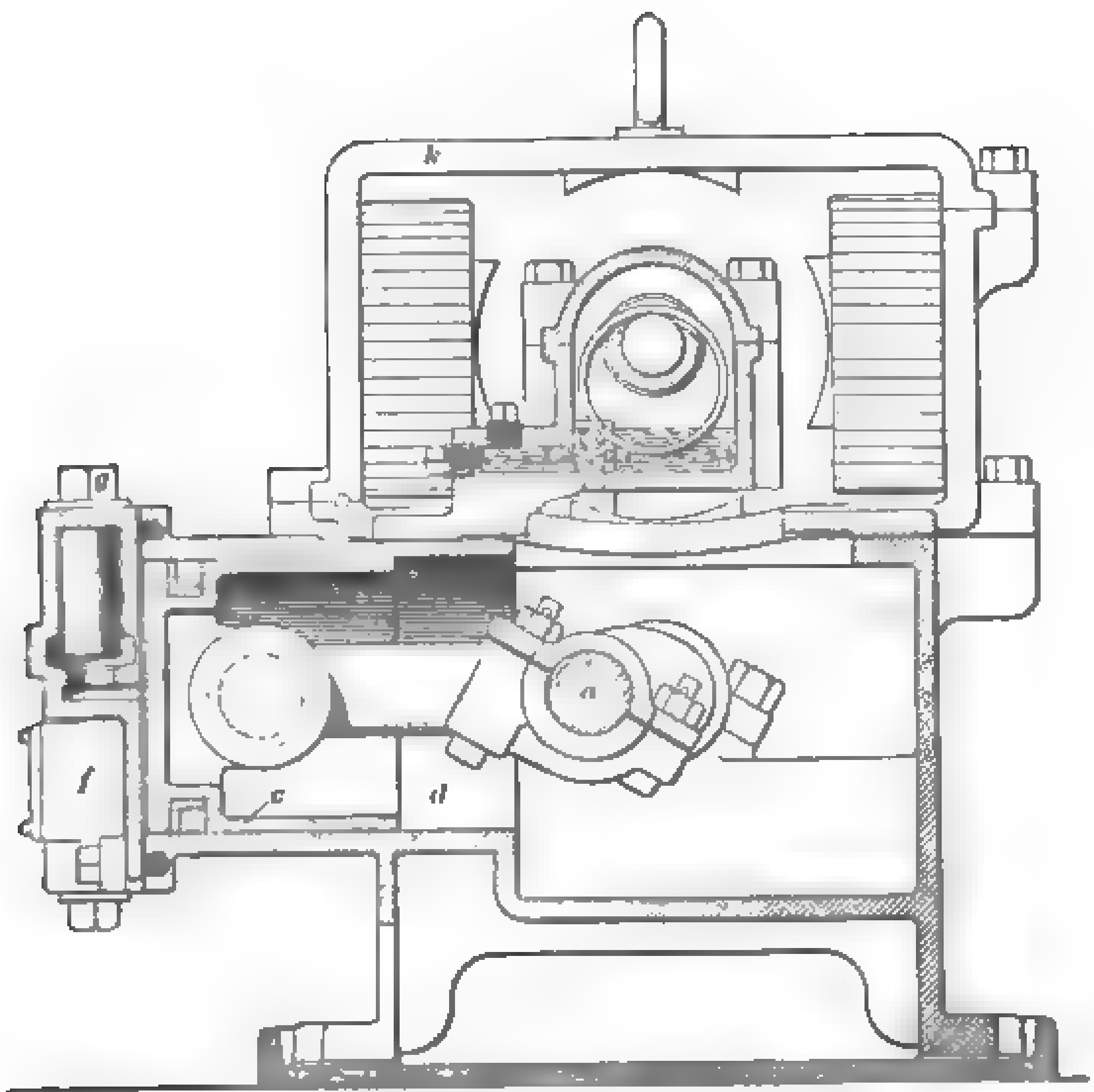
**50.** The compressor made by the General Electric Company is a departure from usual practice, in that it is driven through neither a worm nor a gear, the air pump pistons being directly connected to a slow-speed motor; also, the



(a)




(b)




(e)

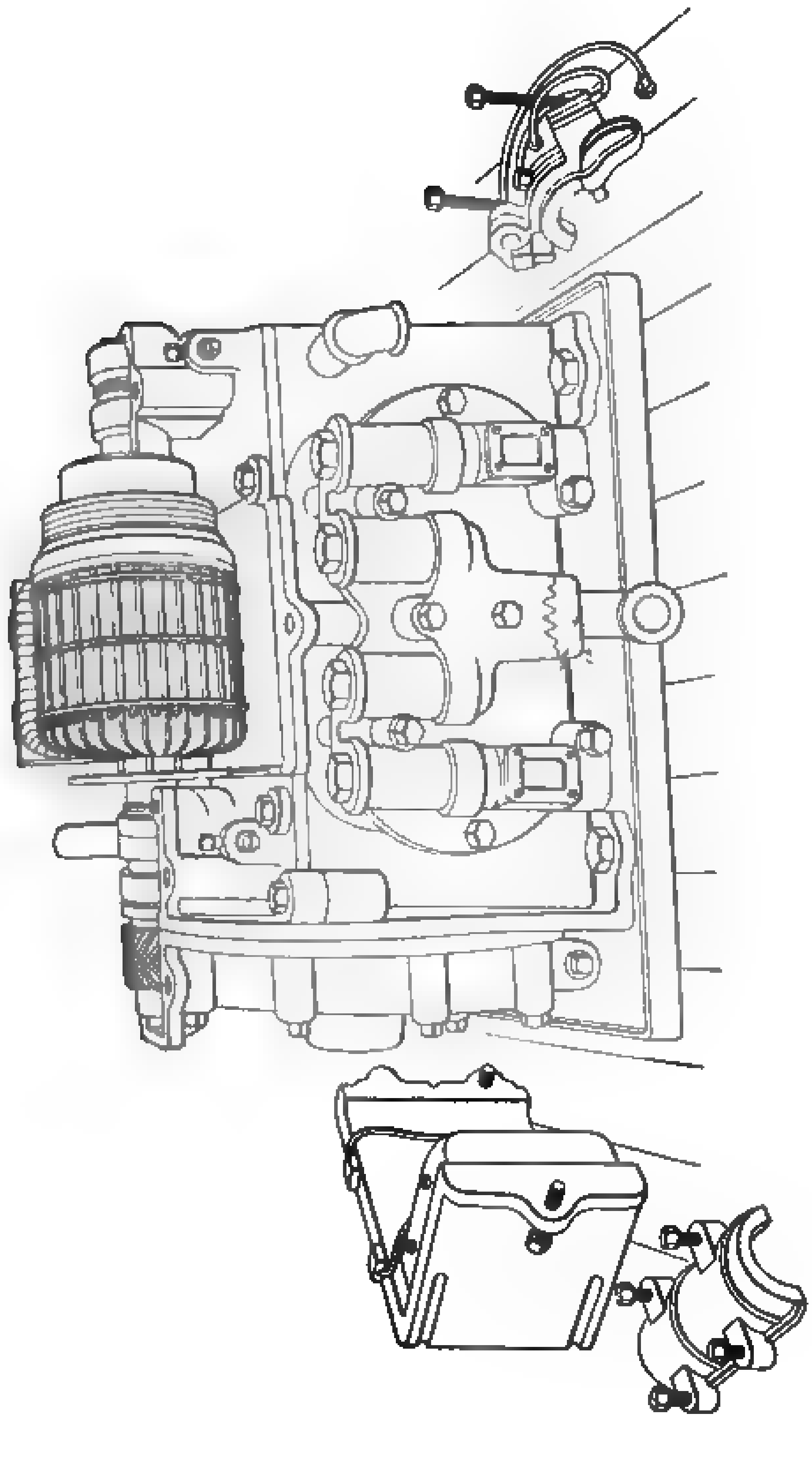


FIG. 51

pump action is compound instead of duplex. Fig. 53 is a sketch of connections showing a section through the governor *G*. Through fitting *a*, air from the reservoir enters chamber *b* behind rubber diaphragm *c*, which presses on plate *d*, the stem *e* of which actuates mechanism *f* and opens switch *g* when reservoir pressure exceeds a certain value; blow-out coil *h* suppresses arcing at the switch contacts. A second pipe (not shown) runs to the engineer's valve or reservoir line, as the case may be. Table III gives data relating to a number of different makes and sizes of air compressors used on electric cars.

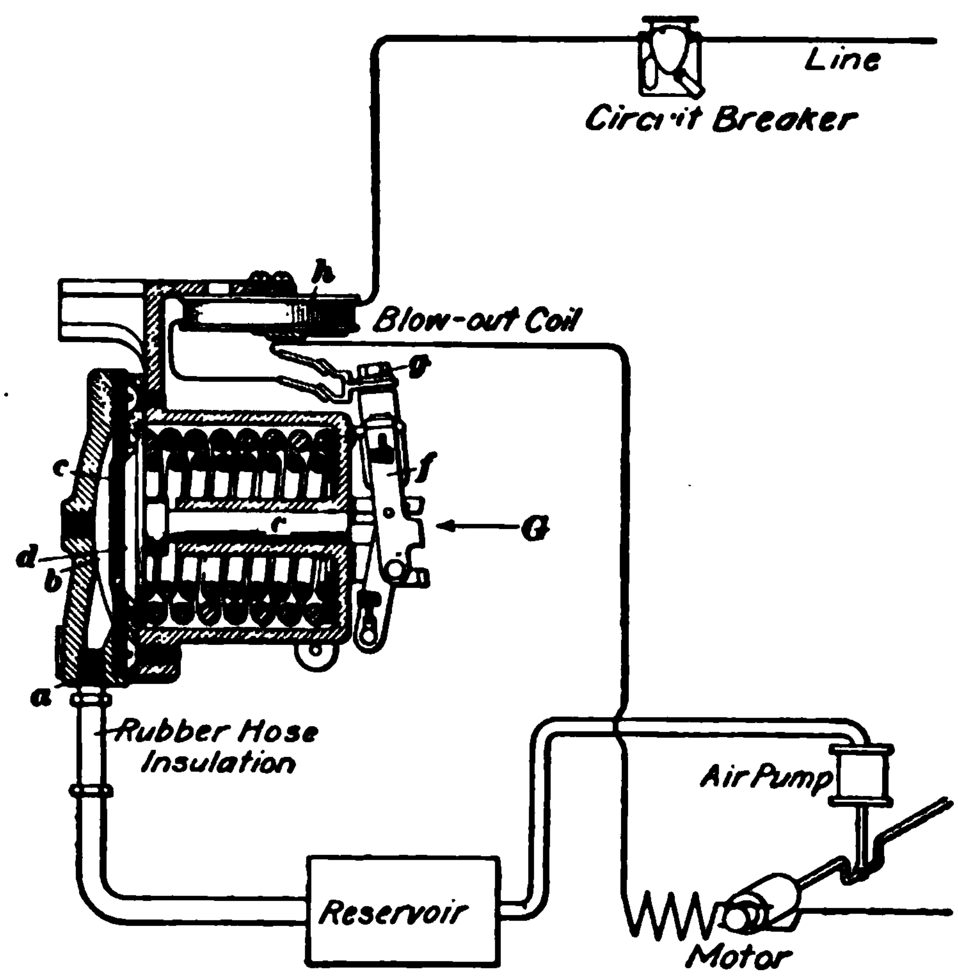



Fig. 53

**51. The Engineer's Valve.**—Fig. 54 is a vertical section through the Christensen engineer's valve, of which Fig. 55 shows the operating positions. The handle can be installed or removed only on *lap position*, so called because on this position all ports in the valve seat are lapped or closed. Movement of the handle to the right until shoulder *m* interferes with it (*service position*) establishes a small opening between the valve ports leading to the reservoir and brake cylinder, bringing the car to a gradual or *service stop*. If the handle is forced to the right as far as it can go (*emergency position*), a large opening is created through which reservoir air rushes to the brake cylinder, bringing the car to an *emergency stop*. On the first position to the left of lap, a small opening is created between the brake cylinder and atmosphere, allowing the brake to release gradually; this position

## TABLE III

### CAPACITY OF MOTOR-DRIVEN AIR COMPRESSORS

| Name of Compressor | Cylinder Dimensions Inches | Revolutions per Minute | Free Air per Minute Cubic Feet | Horsepower at 90 Pounds | Size of Fuse Amperes | Diameter of Suction Pipe Inch | Diameter of Discharge Pipe Inch | Length Inches | Width Inches | Height Inches | Net Weight Pounds |
|---|---|---|---|---|---|---|---|---|---|---|---|
| General Electric C. P. 14 | $5\frac{7}{16} \times 2\frac{1}{2}$ | 300 | 20 | 5.00 | | | | 28 | $22\frac{3}{4}$ | $15\frac{1}{2}$ | 800 |
| General Electric C. P. 17 | $4\frac{3}{4} \times 2$ | 300 | 12 | 3.25 | | | | $27\frac{1}{2}$ | $19\frac{7}{8}$ | 13 | 600 |
| Christensen A-5 . . . . | $4\frac{1}{2} \times 2$ | 200 | 7.5 | 1.50 | 5 | $\frac{1}{2}$ | $\frac{1}{2}$ | $19\frac{3}{8}$ | 16 | $14\frac{1}{4}$ | 265 |
| Christensen AA-1 . . . | $5 \times 2\frac{1}{2}$ | 195 | 11 | 2.20 | 7 | $\frac{3}{4}$ | $\frac{3}{4}$ | $21\frac{13}{16}$ | $18\frac{11}{16}$ | $16\frac{3}{4}$ | 406 |
| Christensen B-2 . . . . | $6\frac{1}{2} \times 3$ | 175 | 20 | 4.00 | 10 | $\frac{3}{4}$ | $\frac{3}{4}$ | $28\frac{1}{16}$ | $20\frac{3}{8}$ | $20\frac{13}{16}$ | 725 |
| Christensen C-3 . . . . | $7\frac{1}{2} \times 4$ | 175 | 35 | 7.00 | 15 | 1 | 1 | $32\frac{1}{4}$ | $24\frac{3}{16}$ | 23 | 950 |
| Christensen D-4 . . . . | $8\frac{1}{2} \times 4$ | 180 | 50 | 9.50 | 20 | 1 | 1 | $35\frac{9}{16}$ | 25 | $24\frac{3}{8}$ | 1,118 |
| Westinghouse D-1 B . . | $5 \times 2\frac{11}{64}$ | 265 | 13.1 | 3.18 | 5 | 1 | $\frac{3}{4}$ | 26 | $23\frac{1}{4}$ | 16 | 633 |
| Westinghouse D-2 B . . | $5\frac{1}{2} \times 4\frac{1}{4}$ | 243 | 23.4 | 5.40 | 10 | 1 | $\frac{3}{4}$ | $30\frac{5}{8}$ | $27\frac{1}{8}$ | $19\frac{3}{4}$ | 918 |
| Westinghouse D-3 B . . | $7 \times 5$ | 162 | 36 | 9.20 | 15 | 1 | $\frac{3}{4}$ | $33\frac{3}{4}$ | $28\frac{1}{2}$ | $22\frac{1}{4}$ | 1,185 |

is used for gradual releasing and for running and is therefore called the *slow-release* and *running position*. If instead of moving the valve handle to this position after an application it is moved to the extreme left to *quick-release position*, the

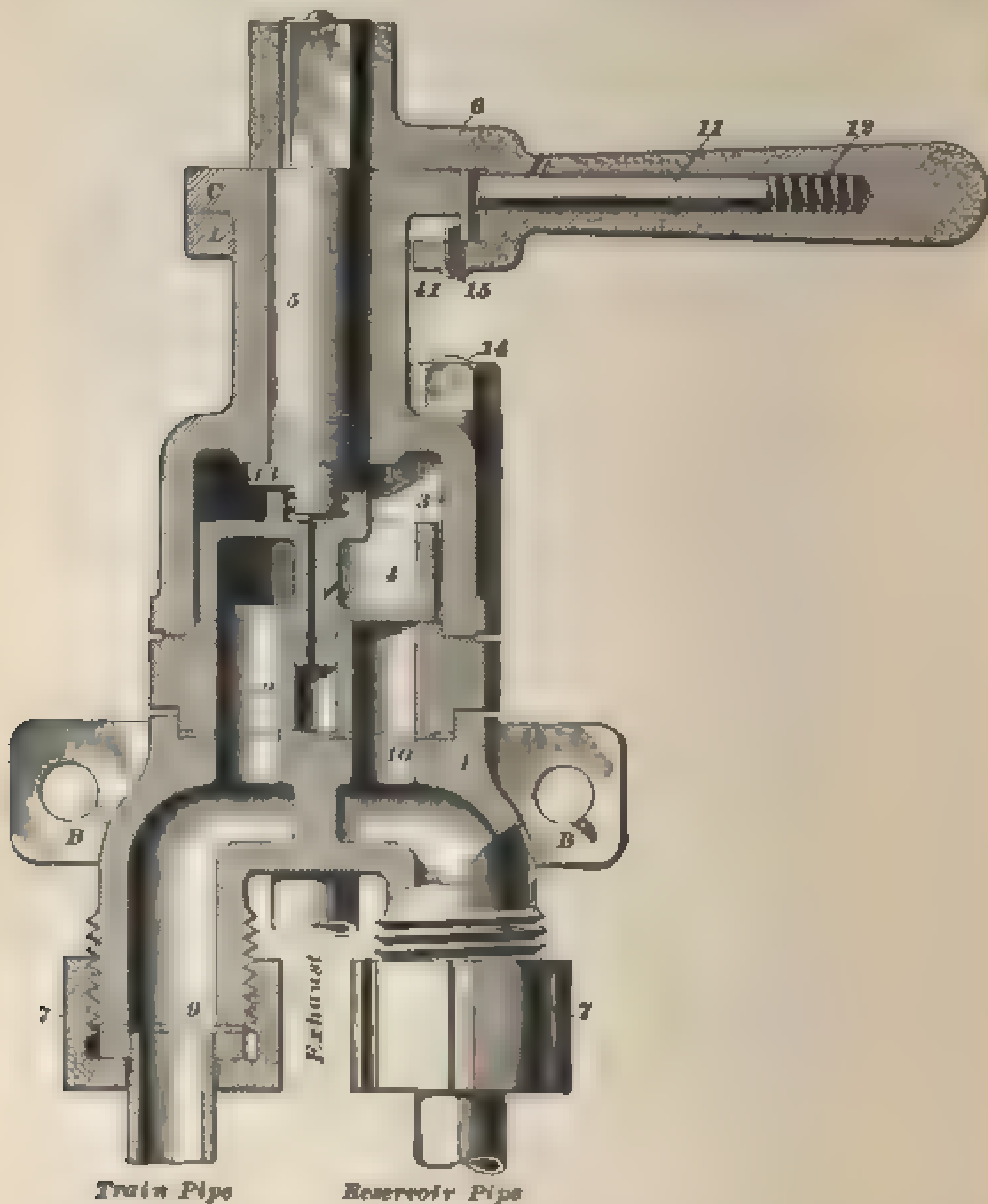



FIG. 54

size of the opening between the brake cylinder and atmospheric ports is such that the brake-cylinder air rushes out, allowing the release springs to release the brakes suddenly. On cars under headway, the valve is kept on slow-release, because the opening here existing between the brake cylinders

and atmosphere precludes the possibility of leakage across the face of the valve admitting air to the brake cylinder to set the brake unknown to the motorman. Quick-release is used for fully releasing the brake preparatory to starting after having made a stop. Slow-release is used for letting some of the air out of the brake cylinder when it is found

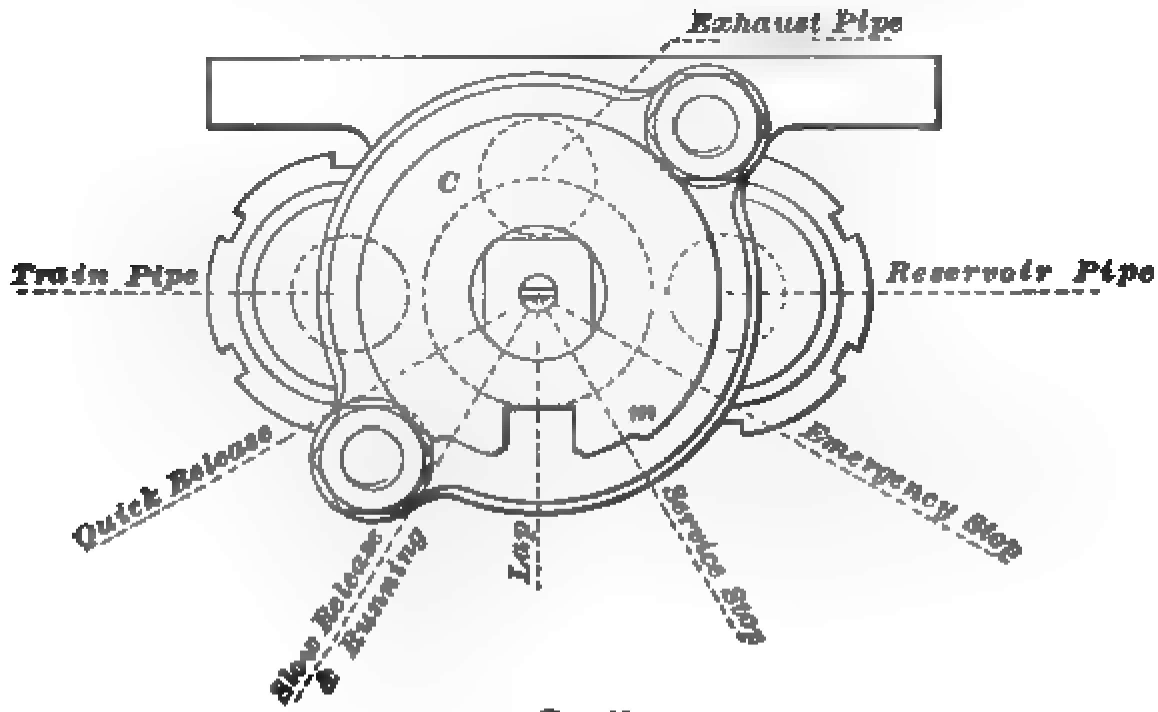



FIG. 55

that the car is going to stop too soon. The emergency position is used only in time of danger, and an emergency application should be accompanied by a liberal application of sand to the rail. An emergency application does not set the brake any harder than a prolonged service application, but sets it more quickly.

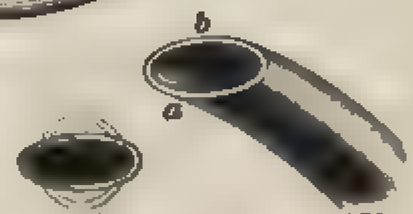
**52.** Each application of the brake reduces the pressure available for the next stop, but if the automatic governor is in order, the pressure cannot fall below a certain amount, for which the governor is adjusted. When the governor is out of order, however, it must be cut out and the starting and stopping of the compressor controlled by hand. Under this condition, the motorman must watch the pressure gauge and pull the switch when the gauge indicates maximum allowable reservoir pressure and close it when leakage or usage reduces the pressure to nearly the lower allowable limit.

The general practice is to allow a margin of 10 pounds, the maximum limit being 60 or 65 pounds and the minimum 50 or 55; there is, however, a tendency toward employing higher pressures—80 to 90 pounds. To reduce reservoir pressure from 60 to 50 pounds requires at least two emergency applications; the number of service applications required depends on the efficiency with which the applications are made and on the local track conditions. Less air is required to stop on an up grade than on a level; less on a level than on a down grade; and less on slippery rails than on good rails, to avoid locking the wheels.

**53.** Valves made by different companies vary somewhat in construction details, some, as in the case of the Christensen, being rotary valves, while others, like that of the Westinghouse Traction Brake Company, being slide valves; all operate to the same end. The off, or lap, position is always the neutral position in which the braking air is held in the condition existing at the time of lapping the valve, and only in this position can the handle be removed or installed—a precaution necessary to insure that the brakes may hold when the motorman removes the handle to change ends on a grade. Air at high pressure is hard to hold, and too much reliance must not be placed on lap position to hold air in the brake cylinder for a prolonged period. A car braked with air should not be left unattended unless the hand-brake has been set. If the handle is left on service position, all air must leak out of both the brake cylinder and reservoir before the brakes will release. If the governor and compressor are cut in and are in good condition, it cannot do this, but the pressure will be maintained at great loss of energy not to mention wear and tear on the compressor.

**54. The Pressure Gauge.**—A pressure gauge indicates the air pressure in the device to which it connects. Where two or more air-braked cars are to be operated together, a gauge having two hands, and called a *duplex gauge*, is used; one hand indicates main-reservoir pressure and the other the pressure in the *train line* or pipe connecting the brake


FIG. 56



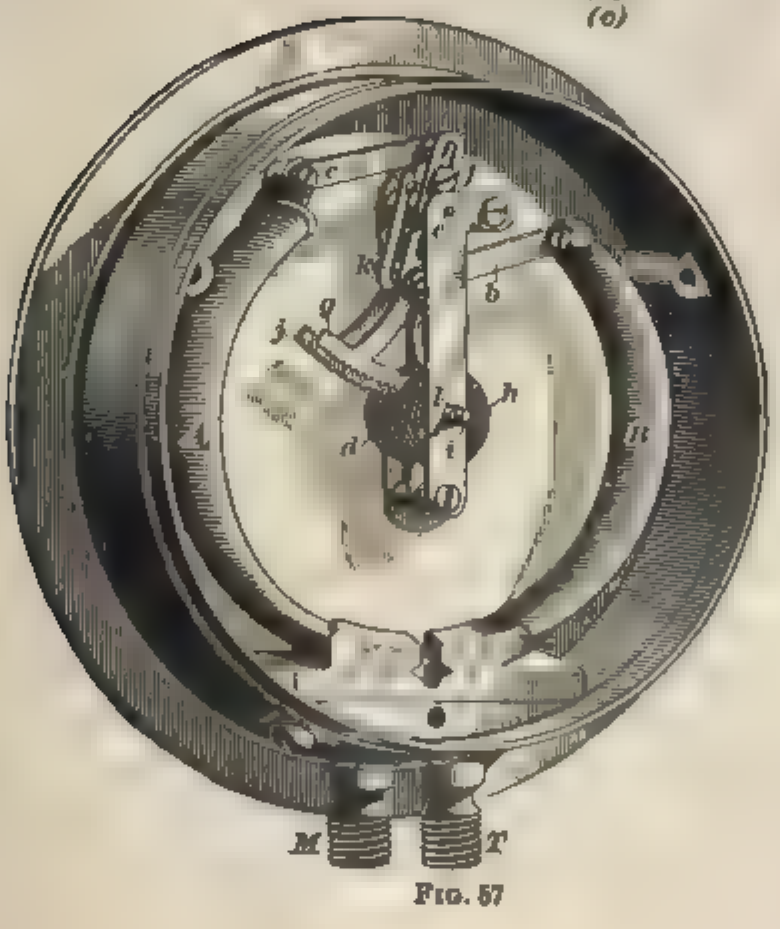
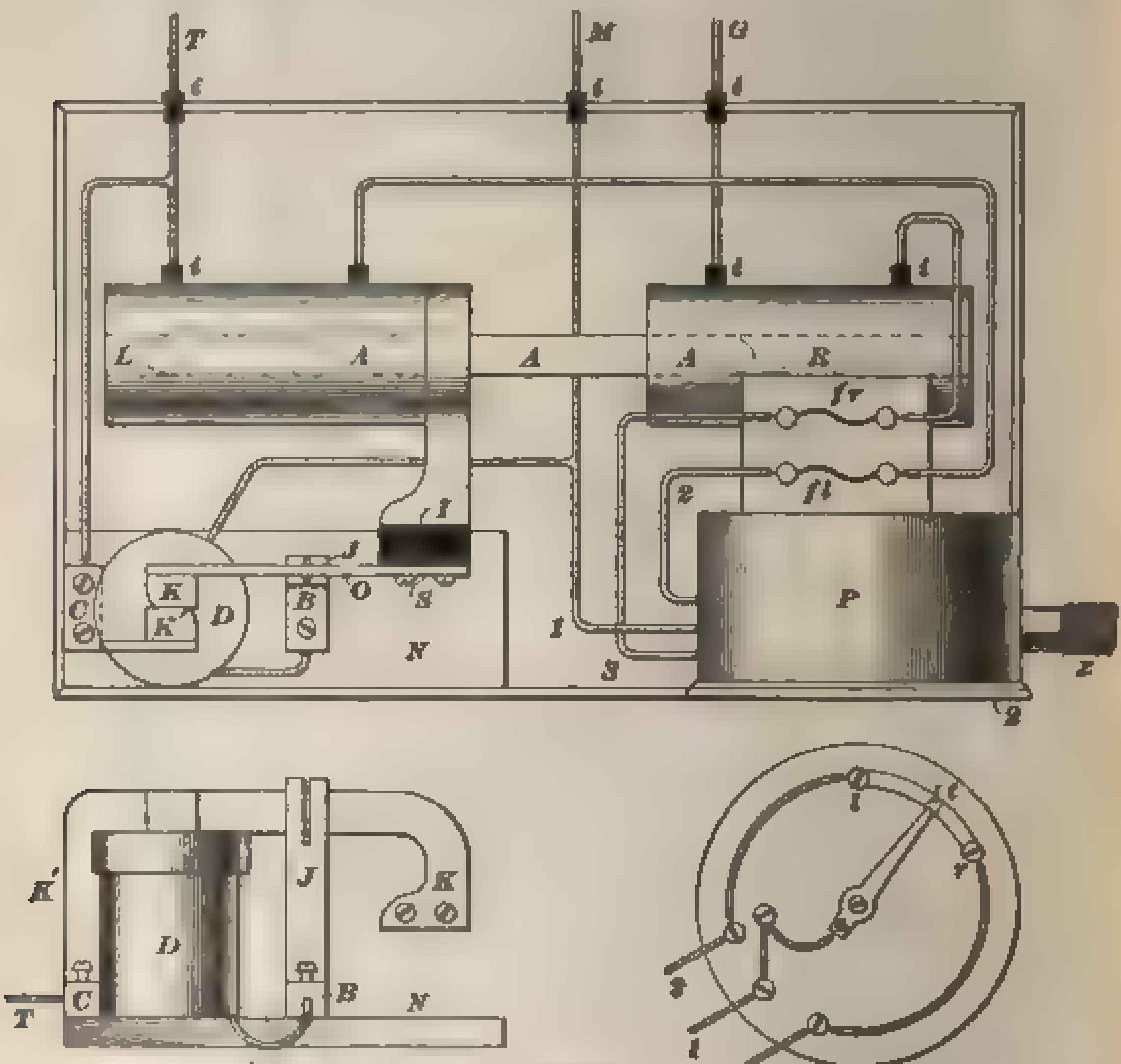




FIG. 57

cylinders together. Ordinarily, single-hand gauges are used on single cars, only main-reservoir pressure being indicated, but a duplex gauge represents the best practice in that it shows at a glance whether the brake cylinder contains air or not, and minimizes the probabilities of starting or running with the brake partially set.




(a) FIG. 56 (b)

**55.** Fig. 56 is a general view of a duplex air gauge, of which Fig. 57 shows the internal mechanism. The thin metal lobes $A$, $B$ have the cross-section indicated in Fig. 57 ($d$), but internal pressure due to the compressed air tends to change them to the dotted cross section of Fig. 57 ($c$), thereby giving the ends of the lobes lateral movement. Through racks $j$, $g$ pivoted at $e$, the end motions of lobes $A$, $B$, respectively, are transmitted to pinions $d$, $h$ on spindles $i$, $l$ concentric with the pinions. These spindles carry the gauge hands, and since

lobe *A* fastens to the rack above the fulcrum and lobe *B* below the fulcrum, both hands move around the dial in the same direction. Connection *M* to the main reservoir admits air to the lobe that operates the red hand, while connection *T* to the train line admits train-line air to operate the black hand.

**56. Automatic Governor.**—Fig. 58 is a top view of the Christensen automatic governor, generally called the pump governor. *L* and *R* are electromagnets in which an iron armature *A* carrying an extension *I* is free to slide. *K* and *K'* are contact fingers, *K'* being stationary and *K* being carried by, but insulated from, extension *I*. *D* is a magnetic blow-out coil through which the current passes and which suppresses arcing when fingers *K*, *K'* are pulled apart. *P* is the regulator constructed on the same principle as a single-hand air gauge; the hand, however, instead of indicating pressure carries on its end a carbon knob *t*, which, according to the condition of main-reservoir pressure, touches contacts *l* or *r*. Connection *x* leads to the main reservoir. Fuses $f_r$, $f_l$ protect the governor magnets. Connections *T*, *M*, and *G* passing through insulating bushings *i* connect, respectively, to trolley, the pump motor, and the ground. The connection to the regulator hand is made very flexible to avoid interfering with the movement of the hand.

**57.** Fig. 59 is a sketch of the connections of the governor of which the operation is as follows: The regulator hand *t* is so adjusted that at minimum allowable main-reservoir pressure, or less, it rests against contact post *l* leading to magnet *L*. Suppose that the reservoir is empty and that it is necessary to get up pressure: On closing the pump switch *K*, current comes in at *T* to junction *X*; if magnet *L* had been the last one to operate, armature *A A* would be at the left end of its travel and fingers *K*, *K'*, Fig. 58, would touch, so that current could take path *X-C-B-D-Y-M-M'-W-G*, Fig. 59, through the pump motor and start it; the current through magnet *L* is negligible because it is practically short-circuited by the path just traced. In this particular case, then, when armature *A A*, Fig. 58, is already in the proper position

coil $L$ does nothing. Suppose, however, that at the time of closing the pump switch, armature $A\,A$ happens to be to the right so that fingers $K$, $K'$ cannot touch; in this case no current can get across the open circuit between $C$–$B$, and the pump motor cannot start at once; but current takes path $X-L-f_l-l-t-Y-M-M'-W-G$, Fig. 59, thereby exciting magnet $L$, causing it to jerk all parts to the left, thereby closing the motor circuit and simultaneously short-circuiting the magnet circuit, as already explained. As the gradually increasing pressure in the main reservoir and hence in the regulator lobe straightens out the lobe, knob $t$ moves from contact post $l$ toward contact post $r$. The instant it touches

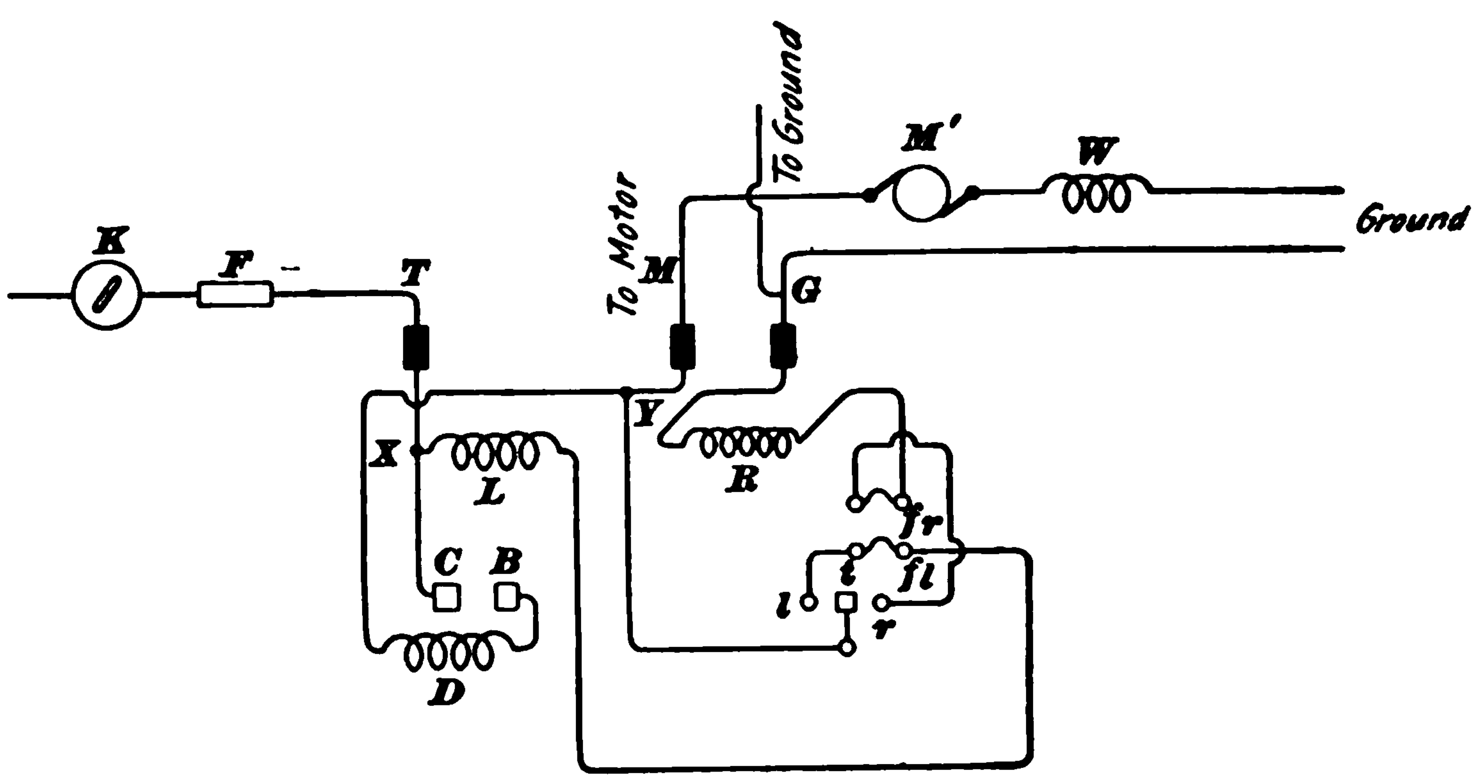



Fig. 59

post $r$, trolley current takes path $T-X-C-B-D-Y-t-r-f_r-R-G$, thereby exciting magnet $R$, which pulls armature $A\,A$, Fig. 58, to the right, opening the motor circuit and simultaneously stopping all current flow through itself. Armature $A\,A$ will remain at the right-hand end of its travel until usage or leakage reduces main-reservoir pressure to its lower allowable limit, when contact between regulator knob $t$ and contact post $l$ will again cut in the compressor.

Connecting posts $r$ and $l$ can be slid back and forth in the circular slot indicated in Fig. 58. By adjusting these posts in the slot, the governor can be made to cut in the compressor at one pressure and out at another.

**58. The Brake Cylinder.**—Fig. 60 is a section through a standard brake cylinder made by the National Electric Company (Christensen Engineering Company). In Fig. 60, *1* is the cylinder body; *2*, the front head; *3*, the back head; *4*, the piston; *6*, *7*, the front and back forks through which pass bolts *15* and *16*, around which turn the cylinder levers of the foundation brake rigging; *8* is the release spring; *11*, the piston packing bolts; *12*, the head-bolts; *13*, the hollow piston stem; *P*, the push rod. At *11* is a threaded hole for the piping to the engineer's valve.

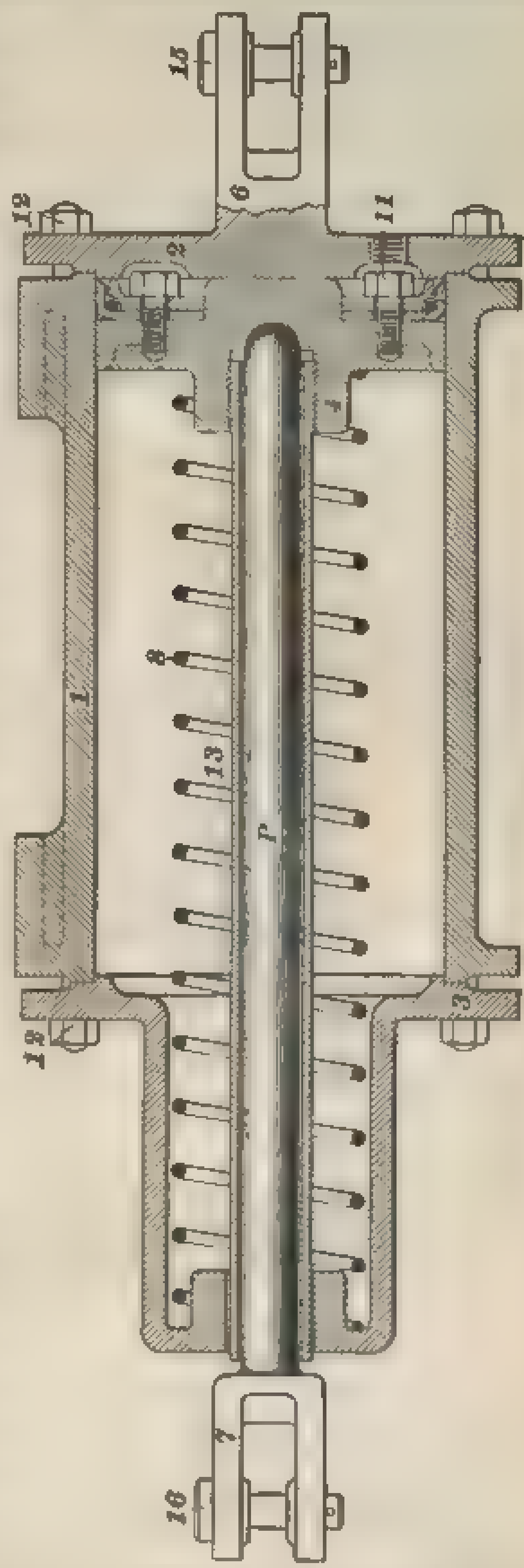


Fig. 60

The operation of the cylinder parts is as follows: Fork *6* is stationary; fork *7* moves back and forth with rod *P*, which operates the cylinder levers. Air admitted through hole *11* forces piston *4* to the left, carrying with it rod *P*, which moves the lever connected to pin *16* and sets the brakes. In moving to the left piston, *4* compresses spring *8*, so that when the brake valve is moved to release position exhausting brake-cylinder air to atmosphere, spring *8* returns piston *4* and

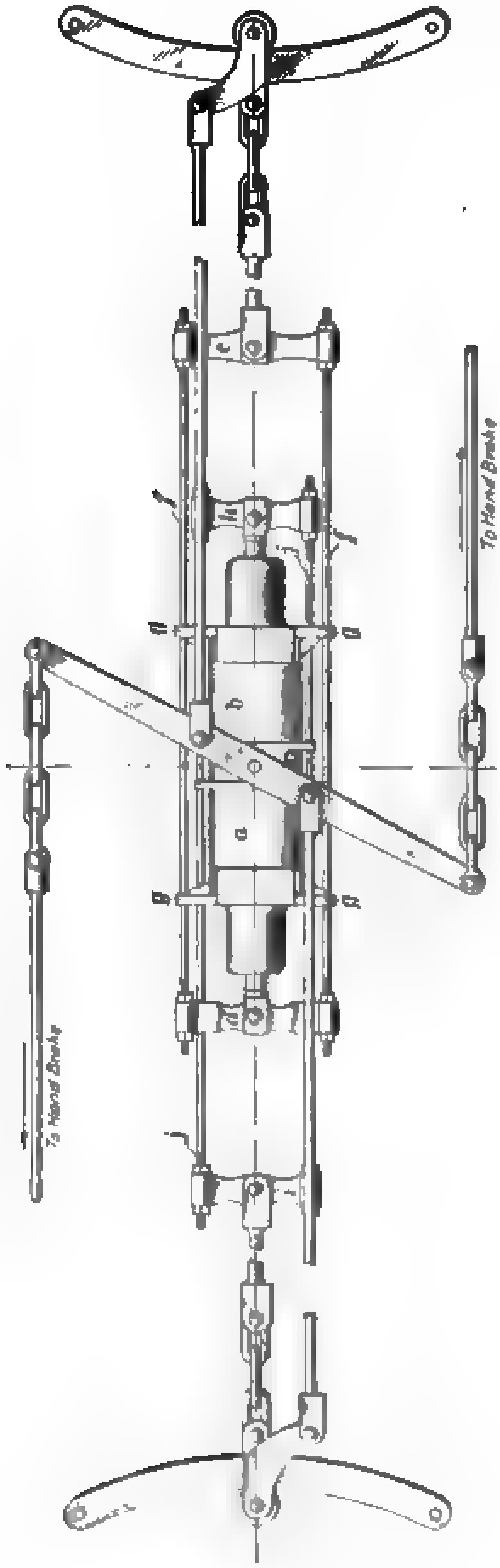



FIG. 61

hollow stem *13* to normal position. Since fork 7 and push rod *P* are independent of stem *13*, the push rod must be returned to normal position by the release springs on the brake rigging. The object of having *P* and *13* independent of each other is that when the hand-brake is used and push rod *P* must be pulled out, it will not be necessary to pull out *4* and *13* against the tension of spring *8*. The brake-piston travel should be kept within the limit prescribed by the manufacturing company, because beyond this limit the side pressure of the push rod *P* will be sufficient to split out the end of the hollow stem *13*.

**59.** Fig. 61 shows a brake cylinder manufactured by the Philadelphia Air Brake Company. As it really consists of two brake cylinders, each with its own piston rigging, it is called a **duplex** cylinder. In Fig. 61, *a* and *b* are the two cylinders accurately alined and bolted together at *c*, by flange bolts (not shown). Crosshead *d*, operated by

the piston of cylinder *a*, is connected to crosshead *e* by rods *f* that pass through guides *g*; and crosshead *h* operated by the piston of cylinder *b*, is connected to crosshead *i* by rods *j*, which also pass through guides *g*. Crosshead *e* is connected, by means of rods, to the arch bar that distributes the pull applied to the truck on one end and crosshead *i* is connected to the arch bar on the other end. When the air pressure is admitted to the cylinder space between the two pistons, they move apart, the one in cylinder *a* applying the brakes on the right-hand end and the piston in *b* applying them on the left-hand end. The breaking of a rod or lever connected with the rigging of one piston does not interfere with the braking power of the other, because the two riggings are entirely independent. The duplex air riggings, together with the independent hand-brake rigging shown, constitute three independent means of braking in an emergency. The duplex arrangement of cylinders simplifies the foundation rigging and equalizes the brake pulls applied to the two trucks without the use of special levers for that purpose.

**60. The Reservoir.**—The reservoir, Fig. 62, is a steel tank generally supported under the car by iron hangers bolted to the sills, but sometimes placed inside the car under the seats or even on the car roof. In cases where space is limited, two smaller reservoirs can be used instead of one

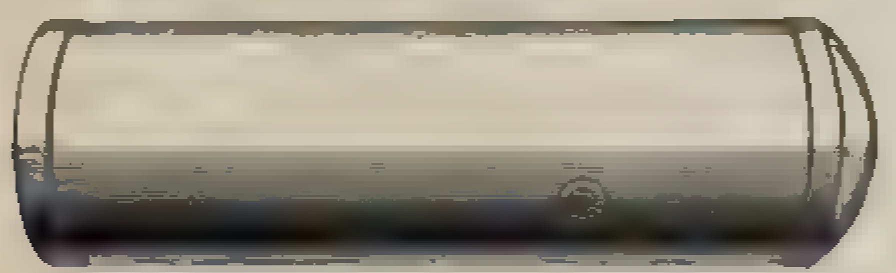
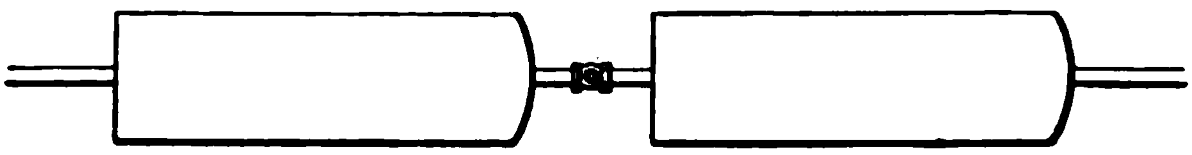


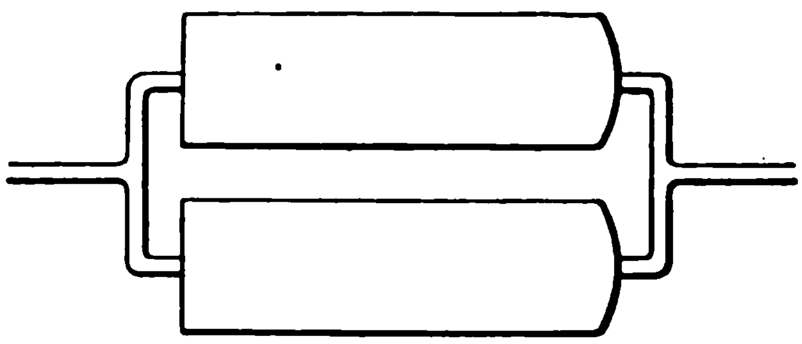
FIG. 62

large one. In such a case the two reservoirs should be piped in series, as indicated in Fig. 63 (*a*), and not in parallel, as in Fig. 63 (*b*). The first connection has the advantage that most condensation takes place in the first reservoir, leaving comparatively dry air to be used from the second one. The greater the capacity of the main reservoir, the higher is the

pressure with which it will equalize with a brake cylinder of given capacity in an emergency application and, hence, the quicker will be the stop. Also, the larger the reservoir, the longer will be the periods of rest and consequent cooling afforded the compressor motor, because once charged to maximum pressure, the greater are the number of applications that can be made without reducing the pressure sufficiently to cut in the compressor. For these two reasons, then, the main reservoir should be as large as practicable. In practice, main reservoirs and brake cylinders are limited to standard sizes adopted by the manufacturers.



(a)



(b)

FIG. 63

**61. Layout of Devices.**—Figs. 64 and 65 show a layout of the Christensen straight air-brake equipment and give an idea of the location and interconnection of devices. If the two drawings are conceived to be held together so that points *a*, *b* on one register with the same points on the other, the result is a complete equipment for a single-end car; and if an extension similar to Fig. 65 be added also to the right-hand end of Fig. 64, the complete layout for a double-end car is the result. In these figures are indicated devices not heretofore considered—pipe and lever connections, coupling and insulation hose, hand-brake, and whistle.

**62.** The **air-brake lever system** is shown in Fig. 64, and consists of front and back cylinder levers *A*, *B* connected by rod *C*. Front and back brake rods *D*, *E* connect at one end to their respective cylinder levers *A*, *B* and at the other

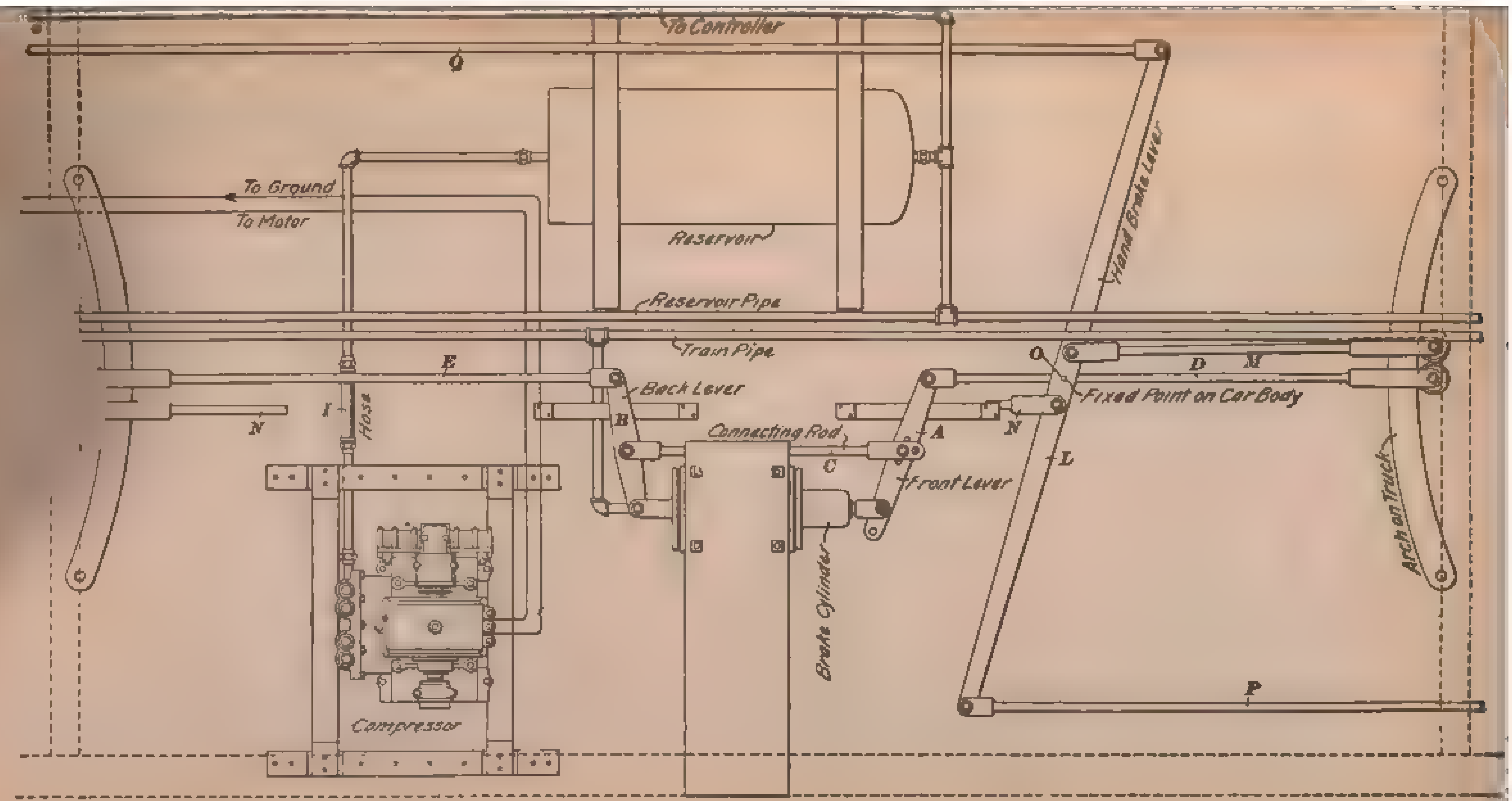

To Controller
Q
To Ground
To Motor
Reservoir
Hand Brake Lever
Reservoir Pipe
Train Pipe
E
O
D
M
Back Lever
Fixed Point on Car Body
I
Hose
N
B
N
Connecting Rod
A
C
L
Front Lever
Brake Cylinder
Arch on Truck
P
Compressor

FIG. 64

end of the car and within easy reach of the motorman, are preferable, so that should the governor get out of order the motorman can conveniently control the air pressure by opening and closing the pump switch irrespective of the end on which he may be operating.

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## STORAGE AIR-BRAKE EQUIPMENT

**67. General Remarks.**—The engineer's valve, brake cylinder, reservoir, and lever system, and most of the piping used on an independent-motor straight air-brake equipment, can also be used on a storage air equipment. In addition to these parts, there must be storage reservoirs, a reducing valve between the storage and service reservoirs, various stop-cocks and check-valves, a charging coupling, and high-pressure gauge.

**68.** Fig. 66 is a diagram of the storage air-brake equipment installed on a double-truck car by the Westinghouse Traction Brake Company. Only one engineer's valve is shown connected, but two are installed where a car is to be operated from both ends. The charging couplings on both sides of the car are connected by a pipe that connects to one end of the high-pressure storage reservoirs. Charging air, at 325 pounds per square inch, on entering either coupling passes through one storage reservoir and then through a cross-pipe to the second storage reservoir. The air passes into the service reservoir through a cut-off cock and an automatic reducing valve, which keeps the service-reservoir pressure constant. The service reservoir connects to the engineer's valve, or valves, and includes a safety valve to insure against abnormal pressure getting into the brake cylinder should the reducing valve get out of adjustment. The gauge that indicates service-reservoir pressure is located in the head of the engineer's valve, a feature peculiar to the valve made by the Westinghouse Traction Brake Company. The gauge that indicates the pressure existing in the high-pressure reservoirs is a separate instrument that connects directly to one of them.

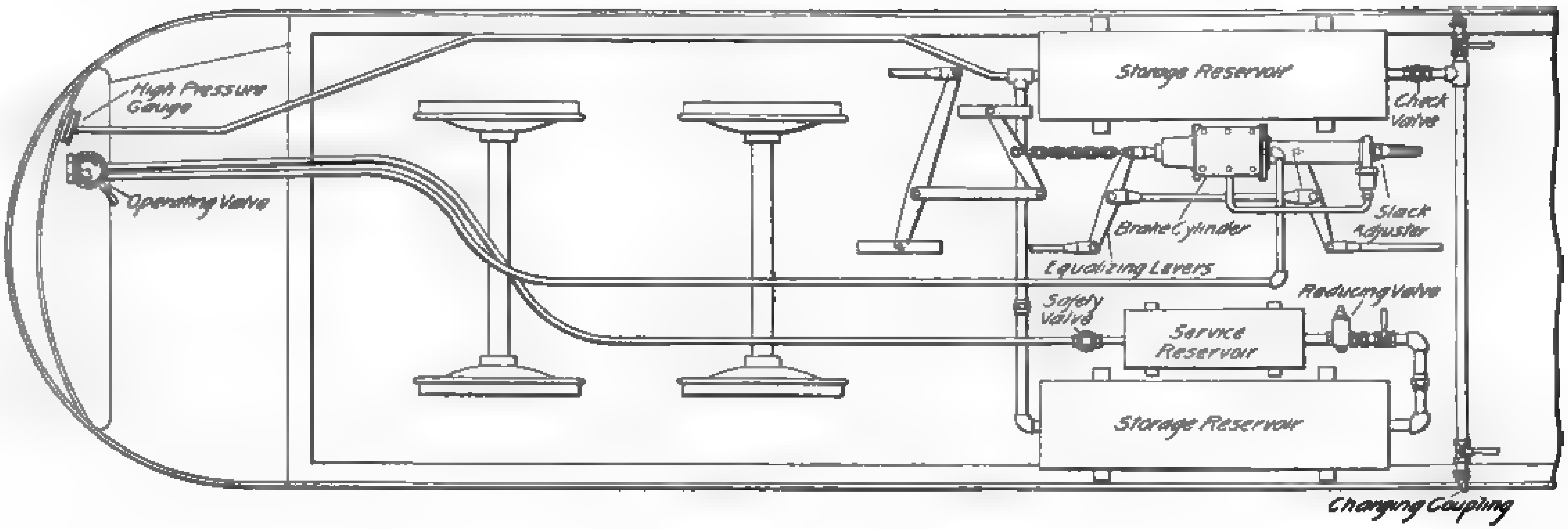

High Pressure Gauge
Operating Valve
Storage Reservoir
Check Valve
Slack Adjuster
Brake Cylinder
Equalizing Levers
Reducing Valve
Safety Valve
Service Reservoir
Storage Reservoir
Charging Coupling

Fig. 66

**69. The Reducing Valve.**—The reducing valve employed for maintaining constant pressure in the service reservoir is the well-known Westinghouse **slide-valve feed-valve** used for maintaining constant train-line pressure on automatic air-brake equipments. In the storage air equipment, the valve body is adapted for pipe connections from the storage and service reservoirs instead of a fitted

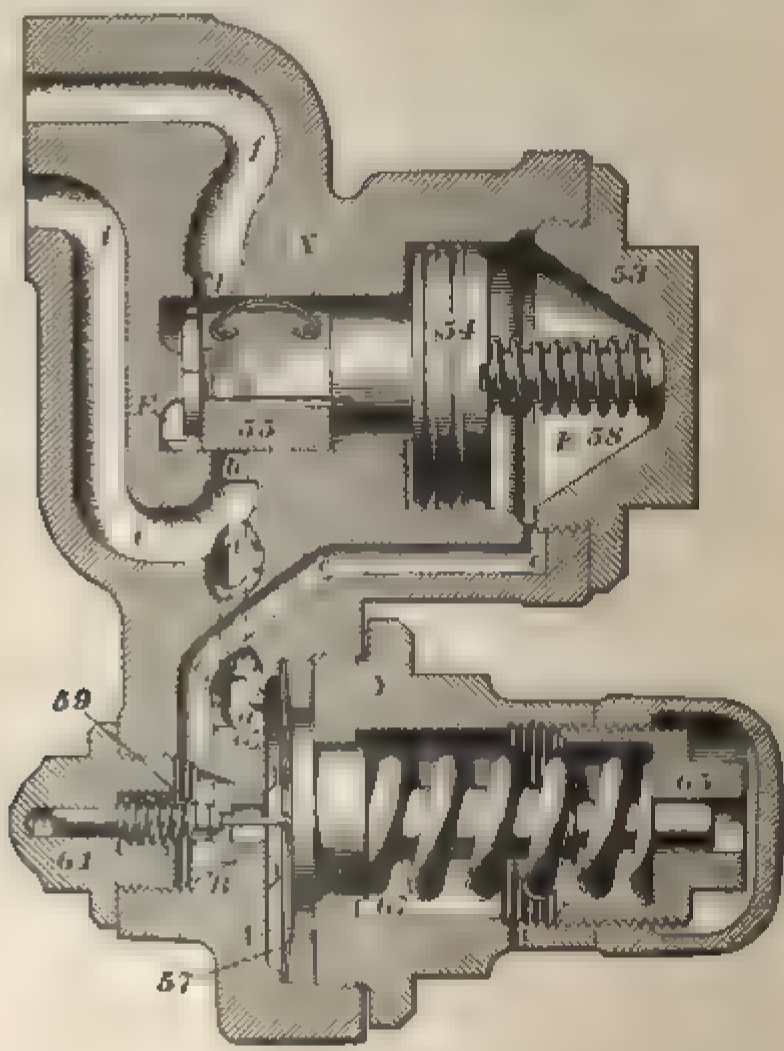



FIG. 67

connection to an engineer's valve. Fig. 67 is a conventional diagram in which the upper and lower valve parts, which are in planes at right angles to each other, have been revolved into the same plane in order to show the ports and passages more clearly. When used as a reducing valve, as on the storage air equipment, the high-pressure reservoir connects to a pipe fitting leading to port *f* and the service reservoir to a pipe leading to port *i*.

The operation of the valve is as follows: Storage-reservoir pressure is in continuous communication with chamber *F* through port *f*; chamber *E*, separated from chamber *F* by supply-valve piston *54*, is connected to passage *i* and thus with the service reservoir through passage *c c*, port *a* (controlled by regulating valve *59*), and chamber *A* over metal diaphragm *57*. Regulating valve *59* is normally held open by diaphragm *57* and regulating spring *67*, the tension of which is adjusted by regulating nut *65*. When open, chamber *E* is in communication with the service reservoir and is subject to service-reservoir pressure. Assuming that usage or leakage has reduced service-reservoir pressure below normal, storage-reservoir pressure in chamber *F* forces supply-valve piston *54* to the right, compressing spring *58*, carrying supply valve *55* with it and uncovering port *b*, through which air passes directly into the service reservoir through passage *i*, *i*, raising the pressure of the service reservoir. This increase of pressure in the service reservoir, hence in diaphragm chamber *A*, continues until it becomes sufficient to overcome the tension of regulating spring *67*, which was adjusted to give at standard service-reservoir pressure. Diaphragm *57* then yields, allowing regulating valve *59* to be seated by spring *60*, thereby closing port *a* and cutting off communication between chamber *E* and the service reservoir. The pressures in chambers *E* and *F* then equalize by leakage past supply-valve piston *54*, and supply-valve piston spring *58*, previously compressed by the relatively high pressure in chamber *F*, now reacts and forces supply valve *55* to its normal position, closing port *b* and cutting off communication between the storage reservoir and service reservoir. A subsequent reduction in service-reservoir pressure reduces the pressure in chamber *A* and permits regulating spring *67* to force regulating valve *59* from its seat, thereby causing the accumulated pressure in chamber *E* to discharge into the service reservoir. The equilibrium of pressure on opposite faces of supply-valve piston *54* being thus destroyed, the higher storage-reservoir pressure in chamber *F* again forces it, with supply-valve *55*, forwards and recharges the

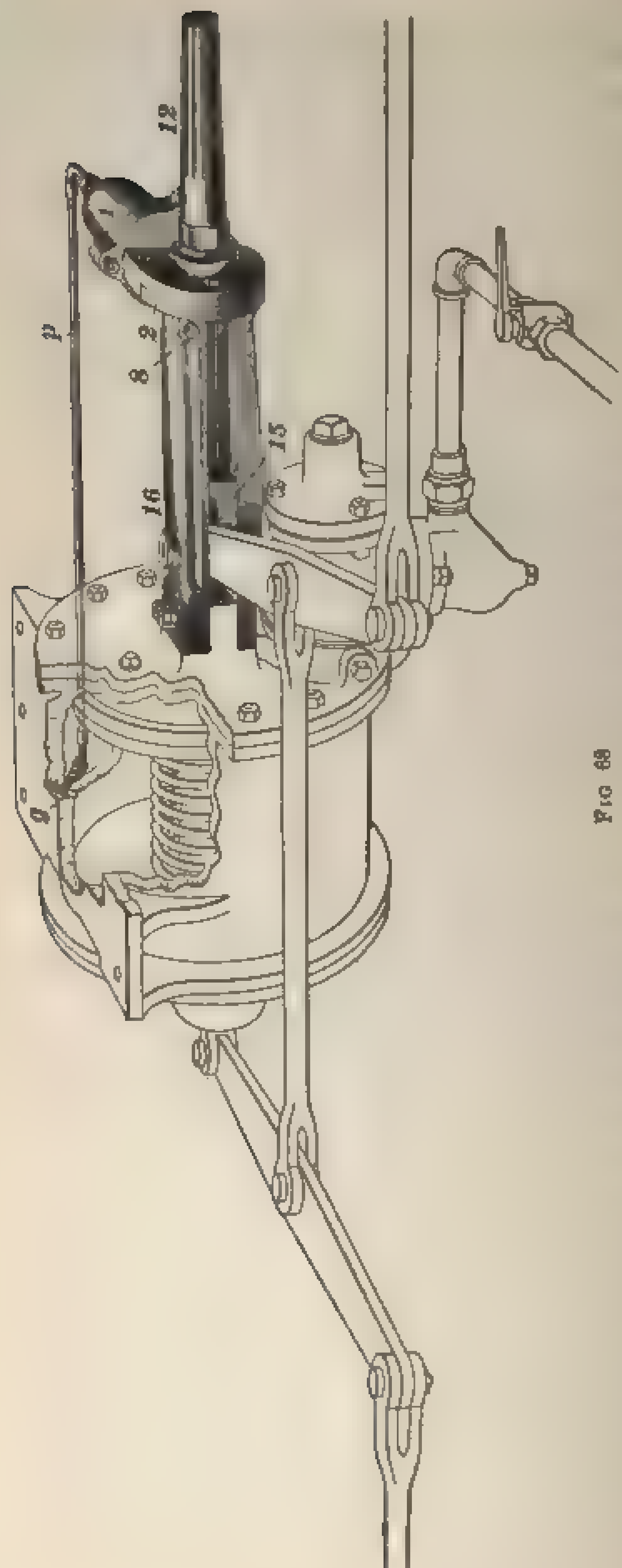



FIG. 68

service reservoir through port *b*, as before. This cycle of operations is repeated whenever usage or leakage reduces service-reservoir pressure below the standard value.

**70. The Automatic Slack Adjuster.**—*Standing travel* is the distance through which the piston travels to apply the brake on a car that is standing; *running travel* is the distance through which the piston travels to apply the brake on a car that is running. Running travel is greater than standing travel and is due to slack in loose-fitting brasses, to the shoes pulling down on the wheels, to play between boxes and pedestals, to clearance between kingbolts and center castings, and to everything that increases lost motion in the brake rigging under the

influence of the motion of the car. Standing travel can be regulated by hand adjustment, and running travel can be indirectly governed, within limits, by allowing for the difference when adjusting the hand travel. Running travel can be actually regulated under working conditions by using a *slack adjuster*.

**71.** Fig. 68 is a general view of the Westinghouse **slack adjuster** applied to a brake cylinder, as indicated in the storage air-brake plan of Fig. 66. Fig. 69 illustrates details of the mechanism. The underlying principle of the device is that a hole is tapped in the brake cylinder and a small pipe *p*

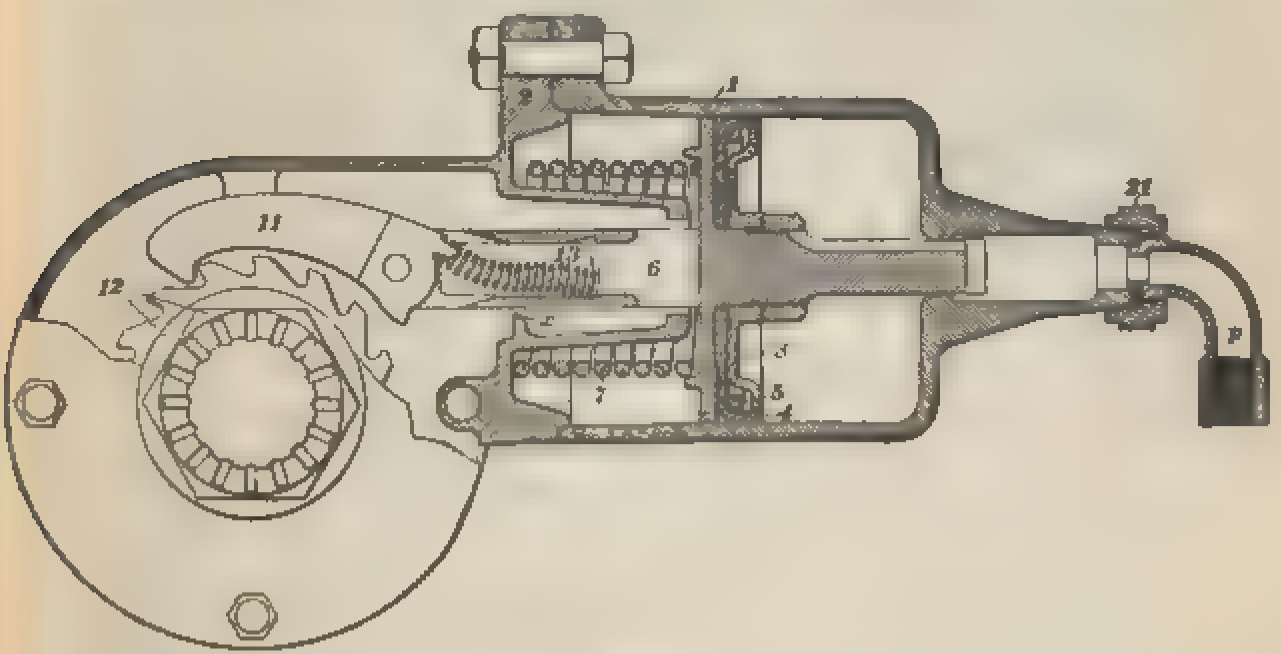



Fig. 69

screwed in it to connect the brake cylinder with the slack adjuster. When the piston travel exceeds a certain predecided amount, it uncovers the tapped hole to the live end of the brake cylinder, permitting some of the brake-cylinder air to pass into the small slack-adjuster cylinder, shown at *2*, Fig. 68, and in detail in Fig. 69.

In Fig. 69, admission of brake-cylinder air to the space behind piston *3* forces the piston and the attached pawl *11* to the left, the pawl dropping on to ratchet wheel *12*, which is mounted on a screw connected to crosshead *15*, Fig. 68. When release of the brakes places the brake-cylinder adjuster port on the atmospheric side of the brake piston, the air in

the adjuster cylinder escapes to the atmosphere and adjuster spring *7* forces piston *3* and pawl *11* back to normal position, the pawl turning ratchet *12* and screw part of a revolution; just before stopping, a heel on the pawl engages shoulder *x*, which raises the pawl clear of the ratchet wheel so that hand adjustment will not be interfered with. The result of this clockwise movement of the screw, Fig. 68, is to move the cylinder end of the brake lever nearer to the slack adjuster, thereby pulling all brake shoes nearer to their wheels so that the piston will not have to travel so far in order to apply them. To create considerable clearance so that a set of new brake shoes can be installed, the extension *12*, Fig. 68, is turned in a counter-clockwise direction; to take up slack rapidly by hand, extension *1* must be turned in a clockwise direction. If a set of new shoes is given proper clearance, the slack adjuster will keep the running travel correct throughout the life of the shoes. To get the best results, the two cylinder levers must make the same angle with the axis of the brake cylinder.

## AUTOMATIC AIR BRAKES

### INTRODUCTION

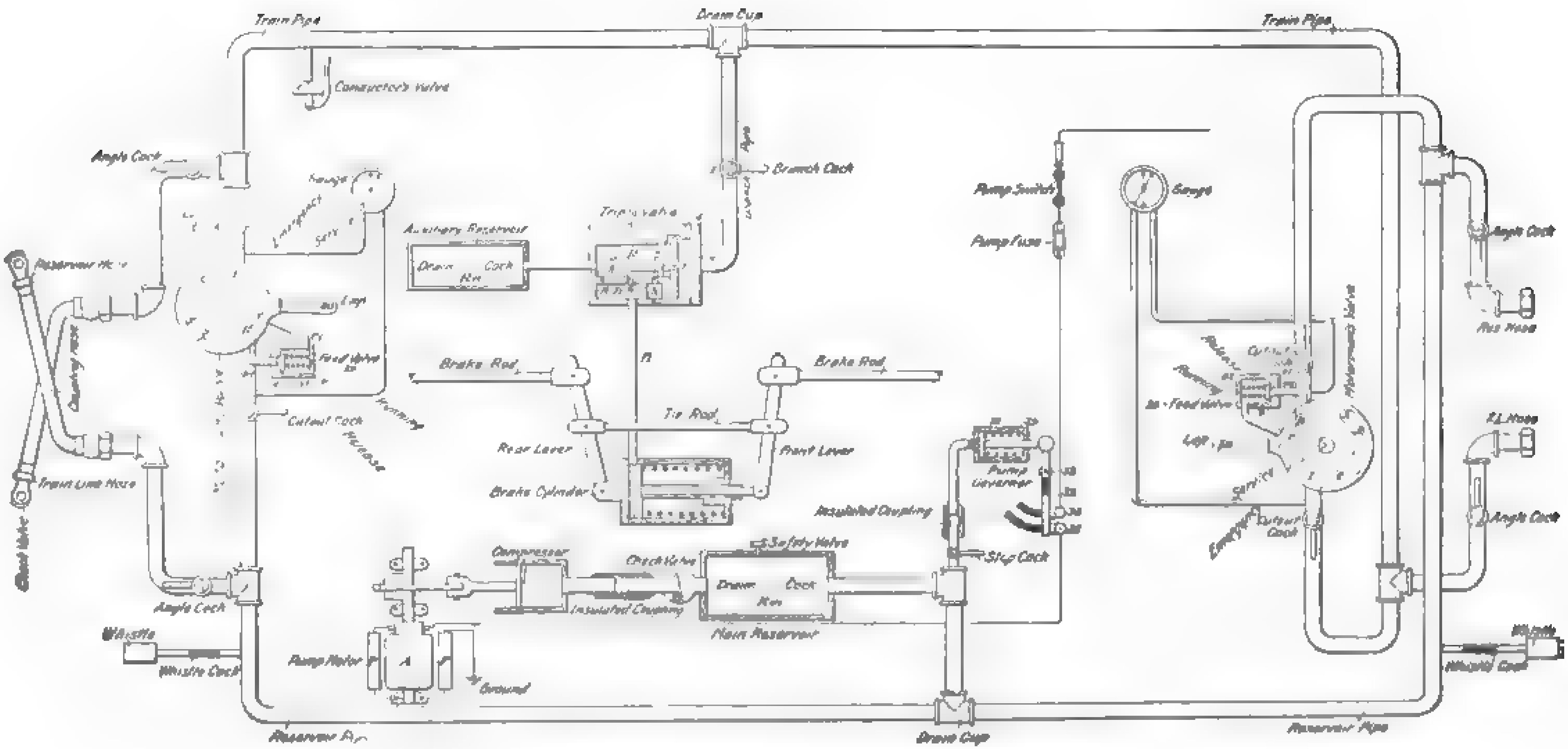
**72.** In train work, *automatic air brakes* are generally used because they are safer, especially on trains of more than two cars. If a train with straight air breaks into two parts, the air brake is useless and the hand-brakes must be applied on both sections. If the train has automatic air brakes, each section will come to a stop at about the same rate and there will be little danger of disaster. Again, comparatively long trains can be braked much more smoothly with automatic air because the brakes apply practically simultaneously on all cars, whereas with straight air there may be enough difference to cause bumping or stretching. In automatic air brakes, the air that does the braking is supplied from a small auxiliary reservoir on each car and the movement of the air from the auxiliary reservoir to the brake cylinder is controlled by a triple valve so that when

the engineer's valve is operated the brakes are applied to all cars simultaneously.

The automatic air-brake devices used on electric trains are in most cases the same as those used on steam trains, but, owing to the substitution of electricity for steam as a motive power, certain devices must be modified. In steam practice, the compressed air is supplied by a steam-driven air pump on the engine; the air is compressed into a main tank located on the engine and the pressure in the tank is controlled by a pump governor also located on the engine. On electric trains on which all motive power is developed on a single car, the arrangement is the same as on the steam train except that the air pump is driven by an electric motor and air pressure is controlled by an electric governor. Where each car of an electric train must be a complete motive-power and air-brake unit capable of operating alone or on any train combination, the arrangement is a little different. An automatic air-brake motor car has all the devices found on one equipped with straight air brakes with the addition of the auxiliary reservoir and triple valve, the functions of which can be understood by a consideration of Fig. 70. The only devices that have not been explained in connection with the straight air-brake equipment are the triple valve and the engineer's valve, which is a little different from that used on straight air cars. Fig. 70 is designed merely to illustrate the operating principles of automatic brakes and no attempt is made to show the actual details of the various parts; a complete description, including all the constructional features of the various devices, is beyond the scope of this treatise.

## DESCRIPTION OF PARTS

**73. The Triple Valve.**—When valve *3* of the triple valve is in the position shown in the diagram, Fig. 70, air from the train pipe can pass into chamber $L$, thence through feed-groove *4* and chamber $R$ to the auxiliary reservoir $R_a$. Train-pipe air will then feed into the auxiliary reservoir until its pressure is the same as that of the train



Train Pipe
Drain Cup
Train Pipe
Conductor's Valve
Angle Cock
Branch Cock
Triple Valve
Auxiliary Reservoir
Drain Cock
Pump Switch
Pump Fuse
Gauge
Angle Cock
Hose
Reservoir Hose
Feed Valve
Brake Rod
Brake Rod
Tie Rod
Rear Lever
Front Lever
Brake Cylinder
Cutout Cock
Release
Train Line Hose
Lap
Service
Emergency
Cutout Cock
Pump Governor
Insulated Coupling
Stop Cock
Safety Valve
Compressor
Check Valve
Insulated Coupling
Main Reservoir
Angle Cock
Whistle
Whistle Cock
Pump Motor
Ground
Reservoir Pipe
Drain Cup
Reservoir Pipe
Whistle
Whistle Cock
Angle Cock

Fig. 70

pipe, under which condition the pressures are said to have *equalized*. The pressure in chamber *R* is then the same as in *L* and the triple valve is said to be in *release position*, because the brake cylinder is in communication with the atmosphere through pipe *B'*, chamber *B*, port *6*, cavity in slide valve *3*, port *7*, and exhaust chamber and port *X*. If for any reason air is drawn from the train pipe, thereby reducing the pressure in the train pipe and in chamber *L* of the triple valve, auxiliary-reservoir pressure in chamber *R* will force triple piston *2* and slide valve *3* to the right; this will first close feed-groove *4* so that auxiliary-reservoir air cannot flow back into the train pipe; then the flat part of the slide valve *3* will close port *6* and then open port *8* so that auxiliary-reservoir air can flow into the brake cylinder by way of chamber *B* and pipe *B'*, thereby setting the brake. This is called *service position*, because it is used to produce a service stop. In order to release a brake that has been thus applied, it is necessary to raise the pressure in the train pipe, and hence in triple chamber *L*, above that in chamber *R* and the auxiliary reservoir, so as to force the triple piston and slide valve back to release position, to recharge the auxiliary reservoir.

**74. The Engineer's Valve.**—The engineer's valve used with an automatic air-brake equipment places the operations of raising or lowering the train-pipe pressure within the control of the motorman. The device marked motorman's valve, Fig. 70, is a conventional sketch showing the general principle. Exhaust ports *X* and *x* in the valve seat connect together and open directly to the atmosphere; ports *R* and *r* do not connect to each other except through *feed-valve 39*. Port *R* opens to the reservoir pipe and *L* to the train pipe. By means of circular cavity *c* in the rotary part of the valve, the motorman can establish any desired connection between the valve seat ports.

**75.** In the figure, the valve handle *30* is shown in *lap position*, the only position in which it can be installed or removed. Lap position is used when it is desired to hold

temporarily to the condition that has been established in the braking system. For example, if it is desired to hold a car or train on a grade, the train is stopped and the valve handle moved to lap position, in which all valve ports are blanked so that there can be no movement of air through the braking system.

**76.** If the valve handle be moved one notch to the right of lap position—to *service position*—cavity $e$ establishes connection between train-pipe port $L$ and service-exhaust port $x$, allowing train-line air to escape gradually to atmosphere. This gradual reduction of train-line pressure causes the triple valves to move to service position, resulting in a *service application* of the brakes throughout a train.

**77.** On moving the valve handle as far to the right as it can be forced (*emergency position*) cavity $e$ connects train-line port $L$ to emergency exhaust port $X$, allowing train-line air to discharge to atmosphere with a rush that causes the triple valves to move to emergency position where the auxiliary reservoirs equalize with the brake cylinders almost instantly, thereby immediately setting all brakes with full force. In the conventional triple valve of Fig. 70 no emergency attachments are shown.

**78.** Movement of the valve one notch to the left (*running position*) causes cavity $e$ to establish connection between train-line port $L$ and charging port $r$. In this position, if the difference between main-reservoir line and train-line pressures exceeds 20 pounds, main-reservoir pressure will lift feed-valve *41* against the feed-valve spring *52* and feed into the train line. Main-reservoir air will continue to feed into the train line until train-line pressure plus the tension of spring *52*, usually 20 pounds, is able to seat the feed-valve. The difference between main-reservoir and train-line pressures is called *excess pressure*. On steam trains, the governor maintains main-reservoir pressure at 90 pounds and the excess-pressure valves or feed-valves are set to keep train-line pressure at 70 pounds. On electric trains employing electric governors that do not cut in or out until a certain

minimum or maximum pressure is attained, however, the excess pressure is necessarily variable. The feed-valve is operative only on running position. If on any position usage or leakage of air reduces train-line pressure below its standard value, as soon as the engineer's valve is returned to running position main-reservoir pressure will open the feed-valve and recharge the train line to standard pressure. As long as the engineer's valve is on running position, all triple pistons are released and all brake cylinders connected to atmosphere so that any tendency of train-line or triple-valve leaks to cause brakes to creep on is offset by the ability of the main reservoirs to supply leaks through the feed-valve.

**79.** To release brakes promptly after an application, the valve handle is moved to the extreme left to *release position;* here cavity $e$ covers ports $R$, $r$, and $L$ and main-reservoir air rushes into the train line through the large and direct opening thus created. Train-line pressure being thus rapidly raised above that of the auxiliary reservoirs, the triple-valve pistons promptly move to release position, allowing the air in all brake cylinders to discharge to atmosphere.

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## FEATURES OF TRAIN HANDLING

**80. Definitions.**—The act of reducing train-line pressure is referred to as a *train-line reduction* or simply a *reduction.* A *service reduction* causes a *service application*, which produces a *service stop.* An *emergency reduction* causes an *emergency application*, which produces an *emergency stop.* An emergency reduction may be due to operation of the engineer's valve, as described, or to a train parting or a hose bursting. *Charging* the train line refers to bringing an empty train line up to standard pressure. *Recharging* the train line refers to restoring standard pressure reduced by making a reduction. *Overcharging* the train line refers to allowing its pressure to exceed standard value when recharging. Overcharging the train line tends to do away with *excess pressure.*

**81. Making a Service Stop.**—In making a stop, an initial reduction of 5 to 7 pounds is made; any less than this may be insufficient to move all brake pistons beyond their leakage grooves, in which case the air delivered by the auxiliary reservoirs through the triple valves to the brake cylinders is wasted. An initial reduction exceeding 7 pounds is not recommended, as it is liable to result in a shock to the train. In the single-application method of stopping, the initial reduction is followed by a series of lighter ones, the braking force being kept on until the train stops. In the two-application method, the initial reduction is followed by a series of lighter ones until the application is such that if held by lapping the valve, the train would stop several car lengths short of the desired point; before reaching this point, however, the brakes are released and the train permitted to roll into the station at reduced speed, when a mild graduated application will stop it at the exact point desired. A given total reduction followed by a full release constitutes one application irrespective of how many times the engineer's valve is moved to service position and back to lap to make the given total reduction. The two-application method is well adapted to close stops, where platform and car gateways must register. After making the first application, the valve is returned to lap position. The second application must follow the first so closely that if the valve is held on release or running position any longer than is necessary to release the triple valves, the train-line pressure will increase considerably above that in the auxiliary reservoirs, which will not have time to equalize through the small triple piston feed-grooves. This condition would mean a loss of air and time in making the second application, because the train-line pressure must be reduced below auxiliary reservoir pressure in order for the triples to operate.

**82. Making an Emergency Stop.**—When danger requires the quickest possible stop, sand is applied to the rail and the valve is thrown to emergency position and *left there* until the train stops or the danger is past, because if thrown

to lap position too soon after an emergency reduction, rush of train-line air from the rear of a long train is liable to kick off the forward brakes; on short trains, such action is not probable. Emergency stops may be produced not only by regular operation of the engineer's valve, but by the parting of a train, bursting of an air hose, or by operation of a safety valve, called the *conductor's valve*, that is located in a conspicuous place in passenger coaches and is supposed to be operated by any one in case of trouble not known to the motorman.

**83. Value of Excess Pressure.**—Excess pressure is provided to insure prompt movement of the triple pistons to release position. After an application, train-line pressure is below auxiliary-reservoir pressure and the triple pistons are on lap position. To force the pistons of a lot of triple valves in good order to release position, standard train-line pressure is sufficient; but when a triple shows a tendency to stick, it is often necessary to admit main-reservoir pressure of 90 pounds into the train line. A tank of given size will hold more air, by weight, at 90 pounds per square inch than 70 pounds, so that carrying 20 pounds excess pressure virtually amounts to increasing main-reservoir capacity without increasing the size of the main reservoir. By carrying an excess pressure, air is efficiently stored at higher pressure and efficiently used at a lower pressure sufficient to meet all requirements.

**84. Releasing Brakes.**—Releasing brakes consists in recharging the train line by placing it in communication with the main-reservoir line through the engineer's valve. When recharging the train line, great care must be taken not to overcharge the train line and thereby destroy excess pressure. If the engineer's valve is left on release position too long, main-reservoir and train-line pressures will equalize. To avoid such a condition, the valve is left on release position just long enough to release the triples when it is placed on running position, so that the recharging may be completed through the excess-pressure valve.

## ELECTRIC BRAKES

**85.** Various methods have been devised for operating brakes on electric cars by means of electricity, but so far **electric brakes** have been used but little in comparison with air brakes. They are all more or less complicated and have not proved to be as reliable or as easily controlled as compressed-air brakes. In most systems the current for operating the brakes is obtained by changing the connections so as to make the motors act as generators, thus making use of the energy stored in the car to supply the power used in braking. This is an economical method, but it throws additional work on the motors, and if they are already loaded to the limit it may cause overheating. This source of current supply allows the application of the brakes even though the trolley may be off the line, but it is obvious that the car can never be brought to a dead stop on a grade by means of such brakes because in order to generate current the motors must be in motion; the hand-brake must, therefore, be applied after the car has slowed down. In the American electric brake, described later, current is taken from the trolley so that the car can be stopped and held on a grade by means of the electric brakes alone.

### GENERAL ELECTRIC BRAKE

**86.** The **General Electric brake** is dependent on the generator action of the car motors. Current generated by the motors is passed through coils wound on a disk-shaped magnet supported by the motor frames; opposite these magnets are armatures in the form of iron disks mounted on the car axles and rotating with them. Excitation of the stationary magnets causes them to attract the rotating armatures, thereby producing friction effective in stopping the car. The value of the braking current is within the control of the motorman up to a limit fixed by an automatic limit switch, which weakens the motor fields when the braking current exceeds the value for which the limit switch is set. The brake-controlling devices are within the regular operating

controller and consist of extra cylinder segments and fingers, together with an auxiliary switch that insures that the motors may always have their fields and armatures connected in the proper relation to generate, irrespective of the position of the reverse handle and of the direction of the car movement. The brake devices are put into action by advancing the controller handle beyond the regular off-position, an amount dependent on how hard it is desired to apply the brake.

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### WESTINGHOUSE ELECTRIC BRAKE

**87.** The **Westinghouse electric brake** also depends on the generator action of the car motors, but the brake itself differs widely in method of application from the one just described. The braking current passes through a coil *c*, Fig. 71, provided with a core terminating in poles to which are attached track shoes *a*, *a'*. Normally, the track shoes are supported a short distance from the rails by springs *d*, *d'*, but

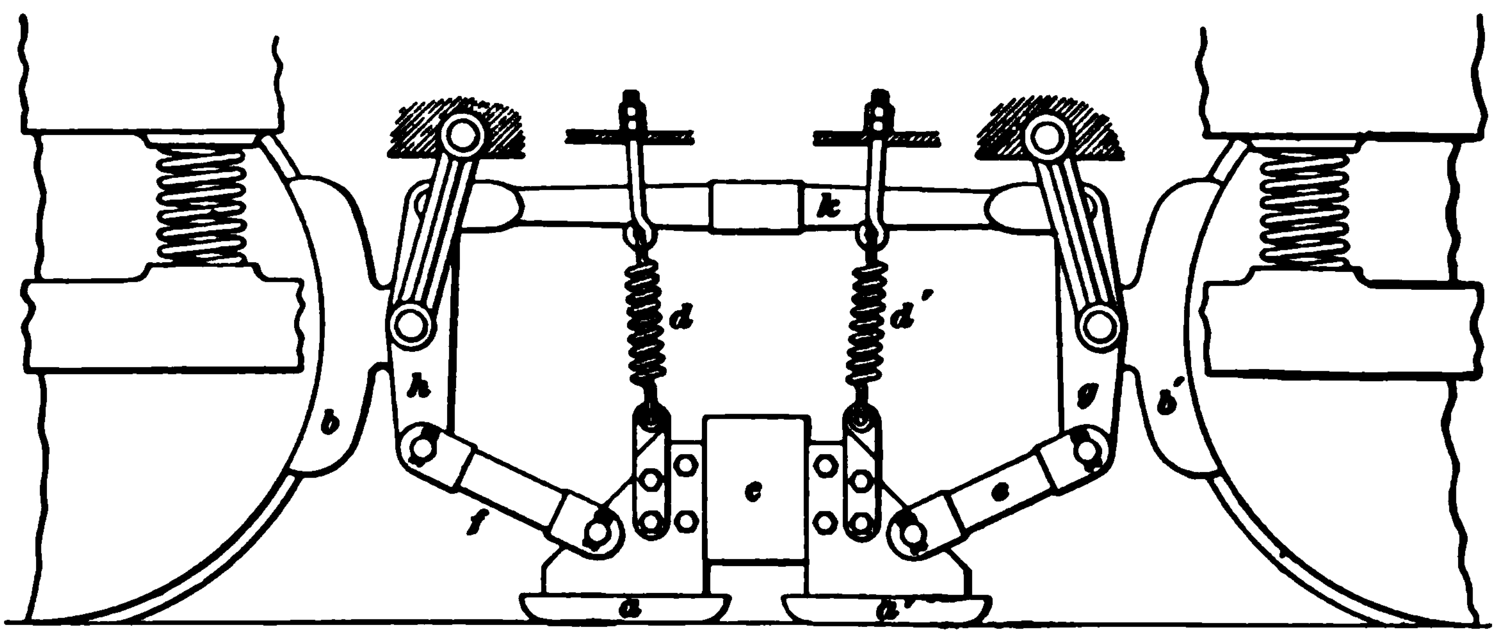


FIG. 71

on sending current through coil *c* the track shoes are drawn to the rail with great force, thereby tending to stop the car; simultaneously, through levers *e*, *f*, *g*, *h*, and rod *k* attached to the track shoes, the regular car brake shoes *b*, *b'* are forced against their respective wheels, thereby applying a second braking force.

The electrical connections are so arranged as to permit of using either the car starting coil or the car heaters as

resistance for regulating the braking current. By using the heaters for brake-current regulation, the heat dissipated is utilized for car-heating purposes. In summer, this system of regulation would make a car uncomfortable, so that on closed cars a switch is provided to enable either the heaters or starting coil to be used.

### AMERICAN ELECTRIC BRAKE

88. The **American electric brake** has several features not found on other electric brakes. At speeds above 4 miles an hour, the braking current is due to the generator action of the motors and to a small line current. At lower speeds, the braking current is supplied from the line, a special relay automatically determining which source of power is to be used. The braking pressure applied to the regular car brake shoes, is due to a solenoid with a plunger so designed that the pull is practically constant throughout its travel. The braking current is applied through a controller standing beside the regular controller, the two being so connected electrically that abuse of the car equipment is prevented. With the brake applied, the regular car controller cannot introduce operating current, and with the power controller applied in full, application of the brake controller will interrupt the motor current before any braking force acts. On account of a special separate excitation feature, the braking ability is independent of the position of the reverse handle and of the direction of motion of the car. Should the brake be applied without the power controller having been thrown to the off-position, it is necessary to return the power controller to off-position before the brake can be released and motor current again introduced.

# MULTIPLE-UNIT SYSTEMS

## INTRODUCTION

### COMPARISON OF TRACTION METHODS

**1.** So far, all the descriptions of electric-car equipments have applied to cars that are operated separately, as in ordinary street traffic. With the extension of the application of electricity to elevated, underground, and interurban roads, there arises the problem of operating cars combined to form trains, as in ordinary steam-road practice. Trains may be operated by means of electric locomotives, in which all the propelling power is concentrated at one part of the train; in this case there is no propelling power on the individual cars making up the train. Or, each car may be provided with its own motors and the propelling power thus distributed throughout the train. A modification of the latter method is to have part of the cars equipped with motors and formed into trains with cars not so equipped. For example, a train might be made up of five cars, three with motors and two without, the train being arranged with the cars in the following order: Motor car, coach, motor car, coach, motor car. In such a train, therefore, the motive power would be applied at three points instead of the front end only, as would be the case if an electric locomotive were used.

A locomotive must have sufficient adhesive force and exert sufficient tractive effort to operate the whole train. The available adhesive force is that due to the portion of the weight of the locomotive that rests on the drivers; the locomotive, therefore, must necessarily be heavy to give sufficient

adhesive force and prevent slipping of the wheels. If each car is provided with motors, a large part of the total weight of the train rests on driving wheels and a large tractive effort is secured without concentrating a great amount of weight at any one point. Electric locomotives are desirable for certain lines of work, particularly in mining operations, where it would be hardly practicable or in fact necessary to equip each car or a number of cars in a train with motors. They are also used in connection with manufacturing plants and for hauling steam trains through tunnels, as, for example, in the Baltimore tunnel.

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### ADVANTAGES OF SEVERAL MOTOR CARS PER TRAIN

**2.** For the operation of elevated or underground trains in cities, the standard practice in America is to use trains made up of cars, each equipped with motors. The conditions under which these trains operate are more exacting than on a cross-country road, because the stops are much more frequent, and as it is necessary to run a large number of trains at close intervals, the problem of starting and stopping the trains in minimum time becomes important. Trains of this character after making a stop must get under headway quickly, and in order to accelerate the train, a powerful effort is required during the period of acceleration. If the train is operated by a locomotive, it is difficult to obtain rapid acceleration, because the weight resting on the drivers is not sufficient to prevent slippage of the driving wheels. With the motive power divided among a number of driving wheels, and with the greater part of the whole weight of the train resting on the drivers, rapid acceleration can be procured without slippage.

The use of individual motors admits of a train being made up of any number of cars, and as each car is equipped with its own driving power, the motor capacity is increased or decreased in proportion to the number of cars to be operated. This allows the size of the trains and the number of motors in operation to be readily changed to suit traffic conditions.

When an electric locomotive is used, the same motors are operated whether or not the locomotive is hauling cars to its full capacity, and as the locomotive must be large to operate a full train, it follows that when a few cars only are used the motors are operated at the low efficiency corresponding to a light load. With the use of motors on each car, safety is insured, because the motive-power units are divided and widely separated, and an accident to one of them does not interfere seriously with the operation of the train. All track and structure stresses are less than with locomotives, because of the more uniform distribution of weight.

3. **Definition of Multiple-Unit System.**—The system of operating trains of cars, each fully equipped with electric motors, brakes, etc., was first developed by Mr. Frank T. Sprague, and has been called by him the **multiple-unit system.** Mr. Sprague's definition of the multiple-unit system is as follows:* "It may be described as a semiautomatic system of control which permits of the aggregation of two or more transportation units, each equipped with sufficient power only to fulfil the requirements of that unit, with means, at two or more points on the unit, for operating it through a secondary control, and a 'train line' for allowing two or more of such units, grouped together without regard to end relation or sequence, to be simultaneously operated from any point in the aggregation." This definition will be more clearly understood after a description of the multiple-unit system has been given.

4. **Elementary Operating Principles.**—Suppose three ordinary surface trolley cars to be completely equipped, but that instead of running the car wires from controller to controller in each car and letting them end there, the wires are run from end to end, tapping off to each controller and putting suitable couplers on the ends, as indicated in Fig. 1, so that the car wires on one car can be made continuous with those on the next, thus producing an elementary multiple-unit train. The main-current motor

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wires will run from one end of the train to the other, irrespective of the length of the train; the train can take current from one trolley pole, or third-rail shoe, or from all the poles or shoes at once, and it can be operated from any controller on any car, whether this car be in the middle or on the end of the train. Every car will do its own share of the work, so that the whole train will start, run, and stop as quickly as a single car. There are, however, several

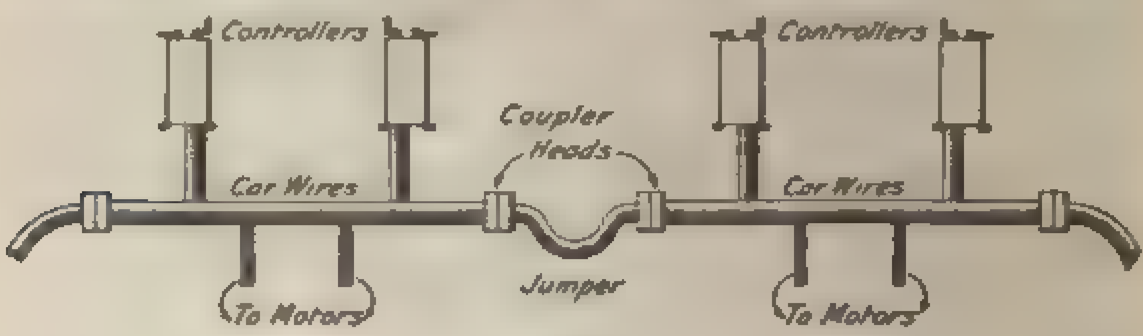



FIG 1

strong objections to a multiple-unit system of this kind: As each controller would be compelled to handle the current required for the whole train, a large and clumsy controller would be necessary; the car wiring would have to be extra heavy to carry the total train current; and it is probable that a satisfactory coupler to transmit such currents would be impracticable. Finally, in case of short circuits or grounds on the car wires of any car, the cut-out devices that would meet all conditions would necessarily be complicated.

**5.** In the multiple-unit system as actually applied these objections have been overcome, and there are at present two prominent systems. The General Electric Company, who acquired the Sprague patents, has brought out a multiple-unit system, which it designates as type M control, that is entirely electrical in its operation. The Westinghouse system for the same purpose is electropneumatic in its operation, compressed air being used to actuate the controllers on each car, and the valves controlling the compressed air being operated electrically.

**6.** In both these systems there is placed on each platform of every motor car a small controller, called the *master*

*controller*, while every car has a *train line*, consisting of a number of small insulated wires made up into a cable and provided with couplers at each end of the car. All the master controllers are connected to this train line, which handles the small current required for the operation of the main controllers. When the train is made up, the train line extends from one end to the other, connecting all the master controllers and the mechanisms that they operate, so that all the main-circuit controllers, and hence motors, can be operated from any master controller. The master-controller circuit is distinct from the main-motor circuit and carries but a small current. The master controller has a number of positions, on some of which the motors are in series and on others in parallel, like an ordinary controller; it is extremely important, therefore, that the main-controller operating devices should respond to the notches of the master controller simultaneously and with precision; for, if the main-motor controllers should feed up at different rates, a condition might arise where the motors on some cars would be in series and those on others in parallel, thus causing trouble.

Each car is provided with its own braking outfit, consisting of an engineer's valve, motor compressor, governor, triple valve, tanks, etc., so that if called on to run alone, it can do so. When a multiple-unit train is started, each car starts, and there is no bumping or jerking as when a train of cars is started by means of a locomotive. There is little strain on the couplings between the cars, and there is therefore little tendency for such trains to break in two. On some roads, for heavy high-speed traffic, the equipment intended primarily for the operation of multiple-unit trains has been used even though the cars are operated singly. On such cars, the amount of current taken becomes so large that it has been found safer and better to operate the main controller through a master controller on the platform. This simplifies the main car wiring, does away with the large controller that would otherwise be necessary on the platform, and also reduces the risk from fire because the main controller and wiring can be arranged and protected so as to reduce the danger of setting

fire to the cars in case of short circuits or other defects. The system is also well adapted to the operation of electric locomotives, large hoists, or other service involving the use of large currents, and particularly for those cases where the controller must be placed some distance from the motors.

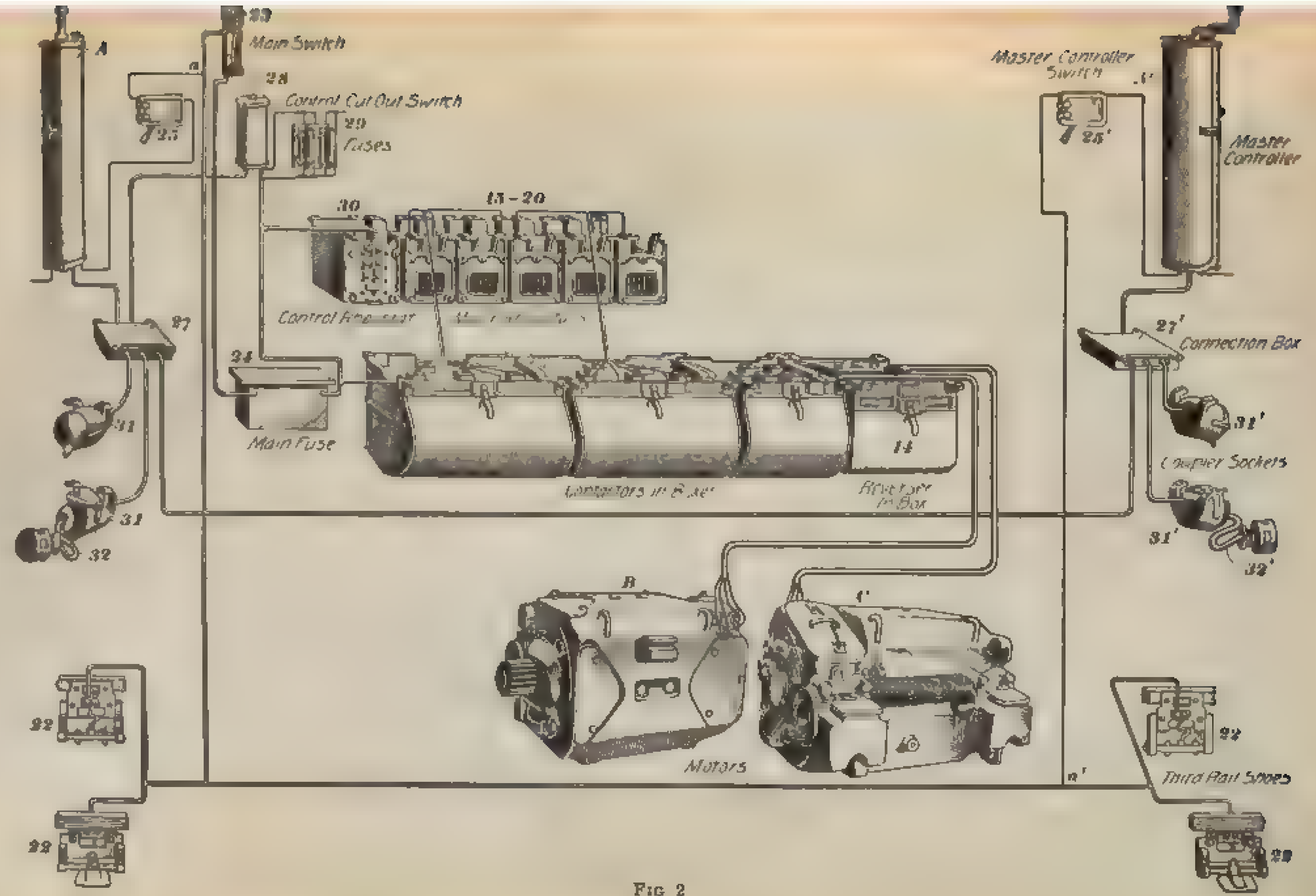
## TYPES OF MULTIPLE-UNIT CONTROL

### SPRAGUE GENERAL ELECTRIC MULTIPLE-UNIT SYSTEM

#### TYPE M CONTROL

**7. General Features.**—The multiple-unit system of control as developed by the General Electric Company, and known as their **type M control,** is wholly electrical in its operation. Fig. 2 shows a general view of the motor-control apparatus installed on each car, and will serve to give an idea of the system as a whole. The master controllers *A*, *A'* are placed on the platforms and control the current that operates the main-motor controller. The latter, instead of being a single device, consists of thirteen electromagnetic switches, or *contactors*, as they are called, and a reversing switch, called a *reverser*, all located under the car in protective housings, as indicated in the figure. The movements of these switches and the combinations of connections that they make are controlled by the master controllers *A*, *A'*. The current that passes through the master controller energizes the operating coils of the contactors and has nothing to do with the main-motor current. The starting resistance used to limit the current flowing through the motor is mounted in the frames *15–20* in the usual manner, and the main current controlled by the contactors is supplied to the motors *B*, *C* through suitable cables.

The main current flows from the third-rail collecting shoes *22*; or if a trolley wire is used, the contact shoes will be



A
Main Switch
28
Control Cut Out Switch
29
Fuses
30
Master Controller Switch
25'
Master Controller
27'
Connection Box
31'
Coupler Sockets
31'
32'
27
24
Main Fuse
31
31
32
14
Motors
22
22
22
Third Rail Shoes


FIG. 2

replaced by the trolley wheel. From 22, the current passes through the main switch 23, by means of which the main current can be cut off; it next passes through the main fuse 24, which is of the copper-ribbon, magnetic, blow-out type. From 24, the current passes to the contactors, reversing switch, and resistance grids, as described later, and finally through the motors $B$, $C$ to ground. At the points $a$, $a'$, the control circuit for each controller is tapped to the main wire from the contact shoe, and switches 25, 25′ allow the interruption of control current through master controllers $A$, $A'$, respectively. From the controllers, the various wires making up the control cable pass to the *connection boxes* 27, 27′, which afford a ready means of connecting or disconnecting the various parts of the control circuit, thus facilitating installation and making it easy to split up the control circuit in case it becomes necessary to locate some defective part. From 27, the local control-circuit wires pass through a cut-out switch 28, by means of which all the operating coils on a car can be cut out in case defects should develop. The fuse block 29 holds four

FIG. 3

enclosed fuses for the protection of the control-circuit operating coils, and the high-resistance rheostat 30 is connected in series with different parts of the control circuit so as to limit the control current to the allowable amount no matter how

many operating coils may be in service. The coupler sockets for making the connection of the control circuit from one car to the next are shown at *31*, *31'*; jumpers for connecting the couplers of abutting cars are shown at *32*, *32'*.

The foregoing will give a fair idea as to the general lay-out of the type M control system. After the various devices have been considered by themselves, the connections and method of operating will be described.

**8. The Master Controller.**—Fig. 3 shows the General Electric C6 master controller with the cover in place, as it appears on the car. The controller, as a whole, is similar in its external appearance to an ordinary type K controller, being about the same height but considerably narrower and occupying much less room. It is located on the platform against the dash rail or vestibule front, in about the same manner as the controller on an ordinary street car.

Fig. 4 shows the controller with the cover removed. The operating handle is shown at *1* and the reverse handle at *2*. The operating handle is not removable, as on an ordinary controller, but the reverse handle is, and when removed the main shaft is locked so that it cannot be turned. The operating handle turns shaft *3*, on the end of which is a gear *4* that meshes with gear *5* on the shaft of main cylinder *6*. The main cylinder is constructed in the usual manner, except that the contact segments *7* are considerably narrower than on an ordinary controller, the current handled being comparatively small. Contact segments *7* engage with contact fingers *8*, mounted on a finger board in the usual manner. The iron pole piece *9* carries the insulating arc deflectors *10* that pass between the contact segments and fingers when the hinged pole piece is swung into its usual position. The blow-out coil is indicated at *11*. All current handled by the master controller passes through this coil and sets up a magnetic field that suppresses arcing at the contacts. The main cylinder is provided with the usual star, or index, wheel *12*, which, in connection with a spring-actuated pawl, gives decision to the notches.

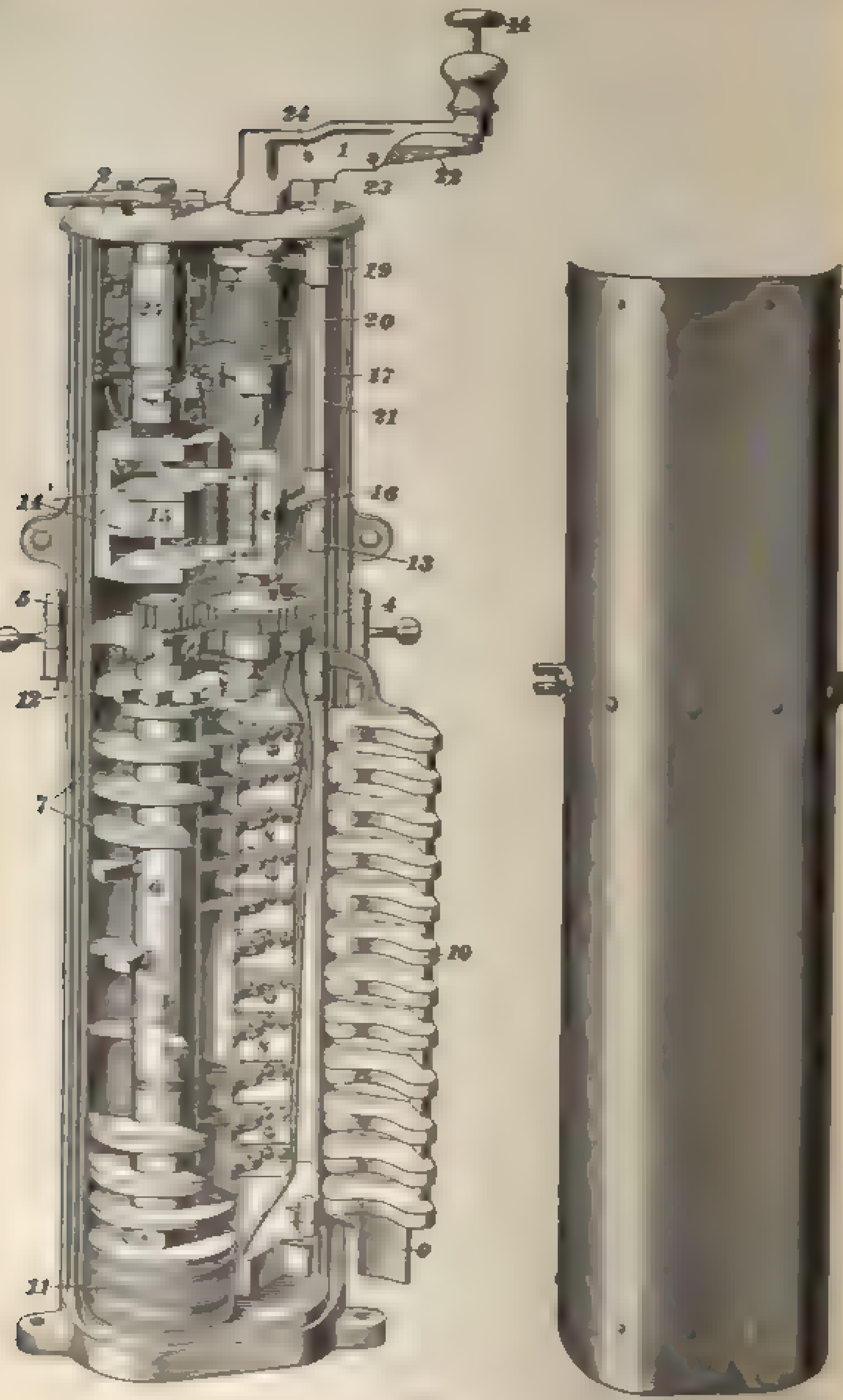



FIG. 4

**9.** The C6 master controller contains a safety switch *13* not usually found on ordinary controllers; it is provided as a factor of safety in high-speed work. To operate the controller and supply current to the motors, it is necessary that the motorman keep knob *14* depressed; if the knob is released, all power is at once cut off from the motors by the opening of safety switch *13*, irrespective of the position of the operating handle; nor can power be applied to the motor circuit again without first restoring the operating handle to the off-position. Should an accident befall the motorman, causing him to release knob *14*, the train will be automatically stopped. On this account knob *14* is sometimes called the dead man's knob, or handle.

Switch *13* consists of an insulating block on which are mounted two fingers *14'* connected together by a metallic strip. When the switch is closed, the fingers touch contacts mounted in the recesses above and below the auxiliary blow-out coil *15* cased in insulating material. The insulating block that carries fingers *14'*, *14'* is mounted on the end of an arm *16* fastened to the rock-shaft *17*, which is acted on by a spring that normally holds it in such a position that fingers *14'*, *14'* are swung out from their respective contacts. All the current in the operating circuit has to pass through the safety switch, and unless this switch is closed by fingers *14'*, *14'* being swung in until they touch their contacts, the control circuit is inoperative and no current can be supplied to the motors. The movements of the rock-shaft *17* and switch *13* are controlled by a cam *19* that has a notch engaging a short arm extending from the rock-shaft; cam *19* is mounted loosely on the main shaft. A spiral spring *20* has its upper end attached to *19* and its lower end to collar *21*, which is firmly fixed to the main shaft *3* and rotates with it. If handle *1* is turned, without pressing down knob *14*, the main shaft *3* and drum *6* are turned, but cam *19* does not turn, because it is mounted loosely on the shaft and is prevented from turning by the projecting arm on rock-shaft *17*. Under these conditions, therefore, spring *20* merely twists or untwists, and since switch *13* is not closed,

the control circuit is inactive. If, however, knob *14* is pressed down before handle *1* is turned, a small dog, or catch, is pressed down and locks cam *19* to shaft *3*. This dog is forced down by means of lever *22*, hinged at *23*, which engages a second small lever hinged at *24* and mounted within the handle. When cam *19* is thus locked to the main shaft, it forces the rock-shaft *17* to rotate through a small angle just as soon as handle *1* is moved from the off-position, thereby closing switch *13* and allowing current to pass through the controller. Spring *20* is placed in position at the factory under considerable tension, so that there is always a tendency for relative movement between cam *19* and collar *21*. When handle *1* is moved around and *14* pressed down, cam *19* is locked to the shaft and hence moves around with collar *21*. There is therefore no twisting action on the spring and no change in the initial tension. Suppose, however, that knob *14* is released after the handle has been moved around from the off-position; the dog engaging *19* is released, and *19* is then free to revolve on the shaft independently of *21*. As soon as *19* is released, the tension on spring *20* causes it to fly to its initial position, and switch *13* at once opens, thus cutting off all current from the control circuit. Before the catch operated by *14* can be again made to engage with cam *19*, handle *1* must be brought back to the off-position, thereby restoring the tension in spring *20* to the original amount. The safety device not only cuts off the current in case of accident to the motorman, but it prevents it from being thrown on, unless all operating devices are in the starting position For example, if the motors were in parallel and the power cut off by releasing *14*, it could not be turned on again with the motors in the parallel position; the handle would have to be brought to the off-position and the motors worked up to the parallel position through the various resistance steps and series connections.

**10.** The small cylinder *25* in the upper left-hand corner of the controller is the *reverse cylinder*, which controls the

movements of the reverser *14*, Fig. 2, and thus determines the direction of movement of the car. The handle *2* of the reverse cylinder cannot be removed until it is moved to the off-position, and this motion of cylinder *25* operates an interlocking device that locks the main shaft *3* so that it cannot be moved. The removal of the small reverse handle therefore prevents the operation of the car from that controller, so that this small handle in effect constitutes a key to the operation of the train and is taken off and carried by the motorman in case he leaves the controller.

The general construction and operation of the master controller is very similar to that of an ordinary magnetic blow-out controller, the principal distinguishing features being the automatic safety switch and the lighter construction of the current-carrying parts. Some of the controllers are built without the automatic safety feature, as on some roads it is not considered essential.

**11. Controller Positions.**—Fig. 5 is a sketch of the master controller top. There are ten marked positions for the operating handle, but only two of these, *5* and *10*, indicated by marks longer and heavier than the others, are

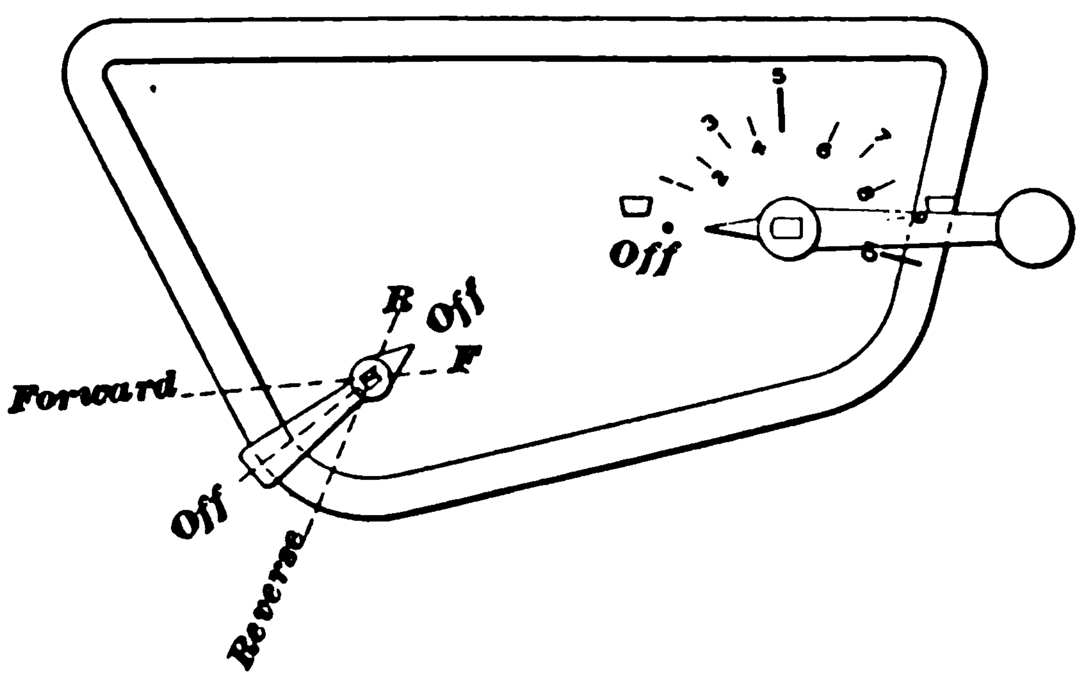



FIG. 5

running positions. On position *5*, the car motors are in series with all resistance cut out; while on position *10*, they are in parallel without resistance. The reverse handle has the usual three positions—forward, off, and reverse—the

arrangement of connections being such that the position of the reverse handle indicates the direction of movement of the car.

**12. Contactors.**—Fig. 6 shows a pair of contactors, the construction of which will be understood from Fig. 7. The design is such that two or more contactors can be grouped together on a common base, as in Fig. 6, thereby simplifying the heavy main-current connections. In Figs. 6 and 7, corresponding letters have the same signification: *a* is the operating coil wound in two sections; *b* is a movable core or plunger; and *c*, a corresponding stationary core.

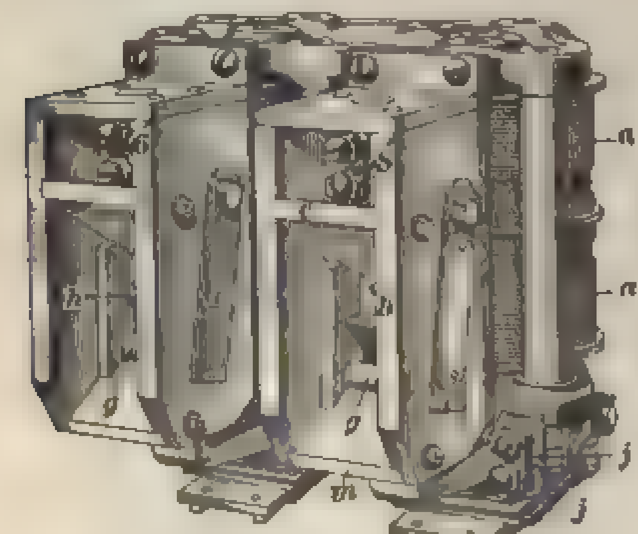



FIG. 6

On the lower end of *b* is hinged a frame *d* that presses on arm *e* through spring *f*. Arm *e* carries on its upper end a contact tip *g* that, when the arm is in the position of Fig. 7, presses against stationary contact tip *h*, thereby closing any circuit of which they may be a part. One main terminal of the contactor is shown at *i*, Fig. 7, and the other at *j*. At *k*, Fig. 7 (*a*) and (*b*), is indicated a blow-out coil consisting of a few turns of heavy bare conductor. Iron pole pieces *l* bolted to both ends of the blow-out coil core *m* direct a strong magnetic field across the region of tips *g* and *h* so that arcing at the contact tips is suppressed. All smoke and gases pass out through a specially provided flue, of which *n* and *o* are the top and bottom walls.

**13.** The operation of the contactor is as follows: In Fig. 6, the contactors are open. The instant that current from the control circuit energizes operating coil *a*, it draws plunger *b* up to the position shown in Fig. 7 and the main-motor current enters the contactor at terminal *i*, passes

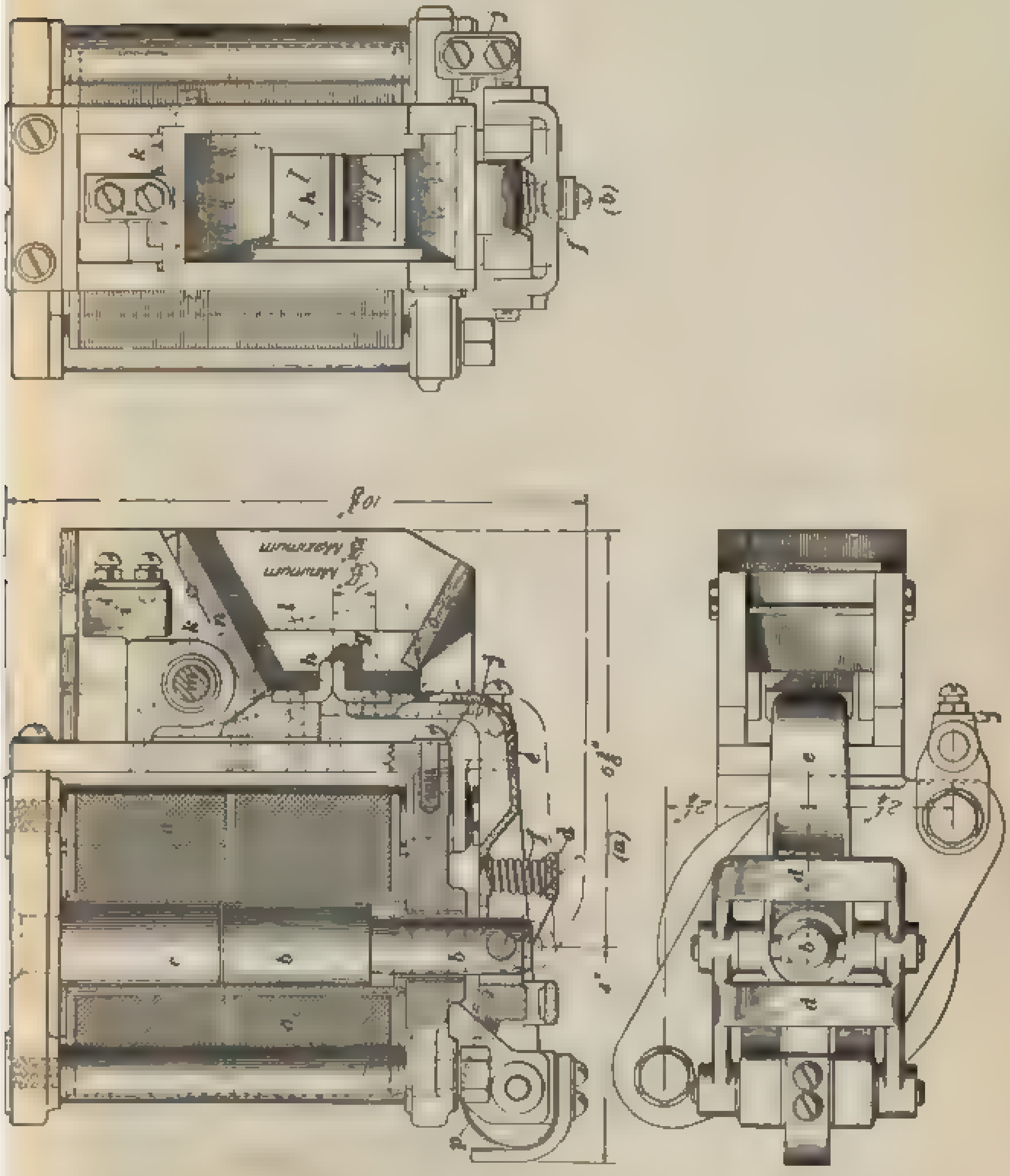



FIG. 7

through blow-out coil *k* to top contact tip *h*, thence through bottom tip *g*, arm *e*, shunt *p*, and the contactor frame to terminal *j*, which is fastened to the frame, on to the next device in circuit by way of the wire connecting to terminal *j*. Spring *f* is instrumental in giving the contact tips a wiping action past each other when the contactor closes, thus making a good contact and preventing the contacts from sticking. The spring also helps gravity to release the mechanisms promptly when the current is cut off from the operating coil.

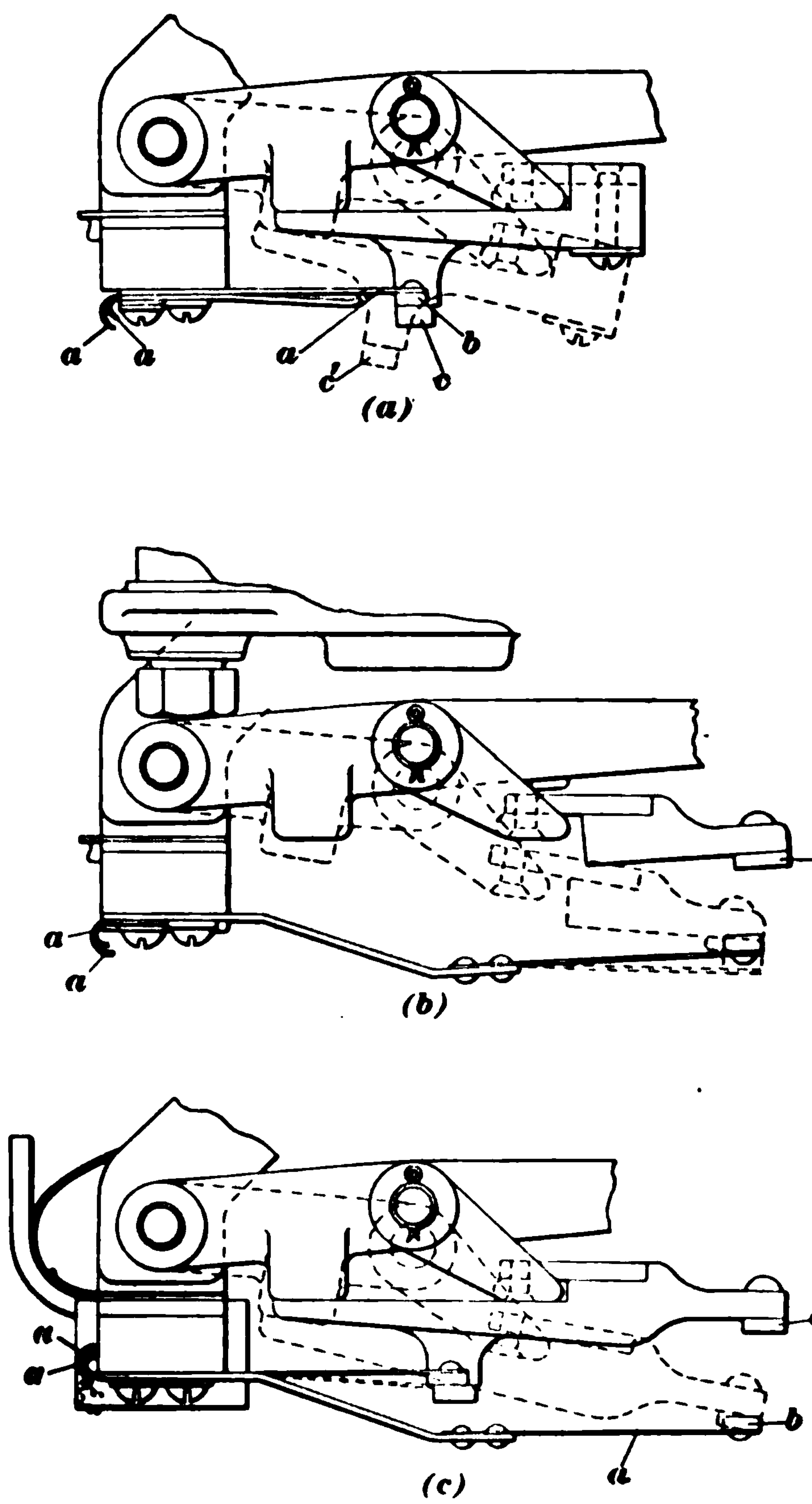


Fig. 8

**14.** On several of the contactors, lever arm *d* is provided with auxiliary contacts called *interlocks*. Some interlocks are so installed and constructed that they will be open when the contactor on which they are mounted is open; others are arranged so as to be closed when the contactor to which they are attached is open, and vice versa. The object of an interlock is to prevent simultaneous action of two circuits in which such action would be objectionable. The general method of attaching the interlocks is indicated in Fig. 8. Small fingers *a*, *a* (the two fingers are in line with each other

so that only one shows in the figure) are attached to the lower part of the contactor frame and carry contact tips *b*. When, in (*a*) for example, the contactor is closed, the metal cross-piece *c* makes contact with the interlock fingers and when the contactor opens, *c* drops to position *c'*, thus opening the interlock circuit. In (*b*), the interlock is closed when the contactor opens; while in (*c*), there are two interlocks, one of which opens when the contactor closes and the other closes when the contactor opens. The interlocks are safety

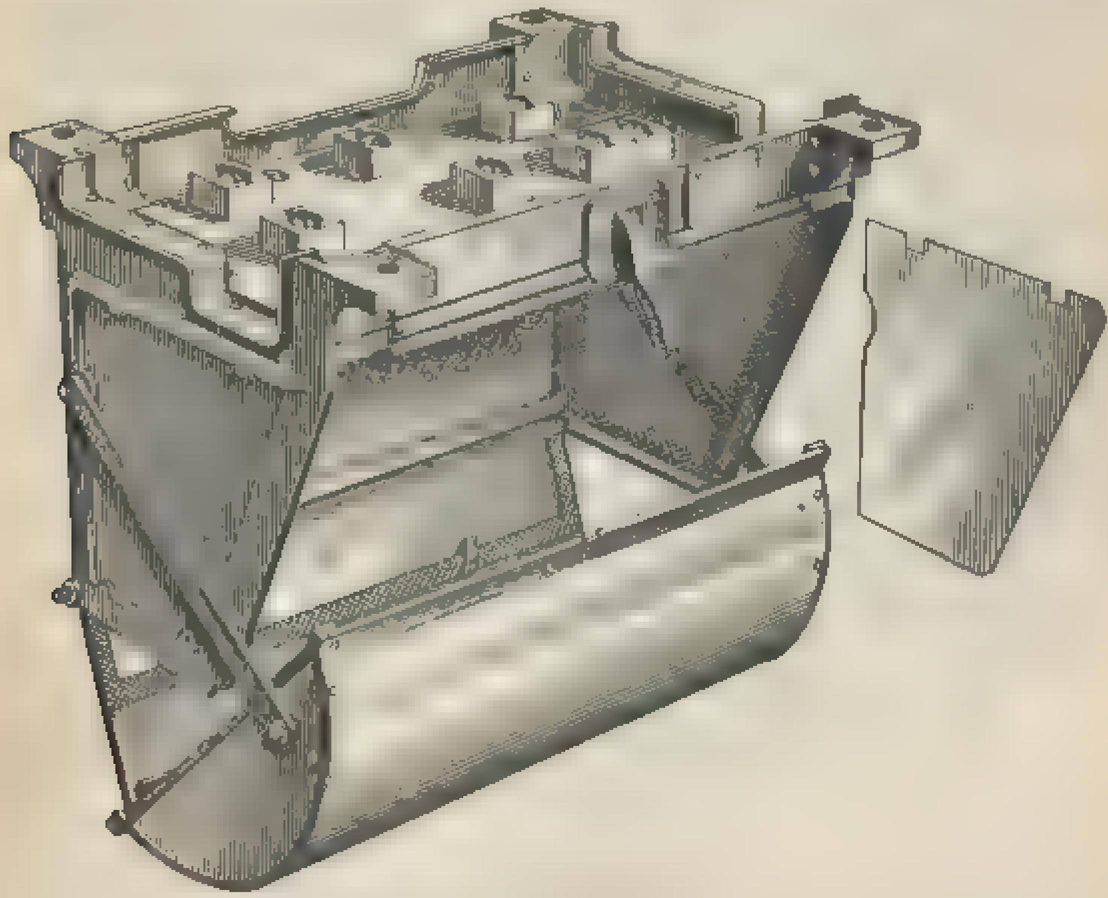


FIG. 9

devices and do not under ordinary conditions open or close the control circuit when current is flowing.

**15.** The location selected for the contactors is usually along one side underneath the car where they will be convenient for inspection and out of the way of other equipment parts. As a mechanical protection for contactors and reversers when installed under the car, boxes similar to that shown in Fig. 9 are used. Figs. 10, 11, and 12 show the arrangement of contactors, which are divided into three

groups and are protected by sheet-iron covers that can be dropped, as shown, to give access to them. The reverser is mounted in a casing by itself at the right-hand end.

**16.** The **reverser** performs the same duties as the reverse switch of an ordinary controller; that is, it controls the direction of the flow of the current through the motor armatures and thereby determines the direction of motion of the car. Each car must be equipped with a reverser, and the movements of all the reversers on a train are controlled by the small reverse switch on the master controller. Fig. 13 is a view of the DB20 reverser, which is mounted under the car

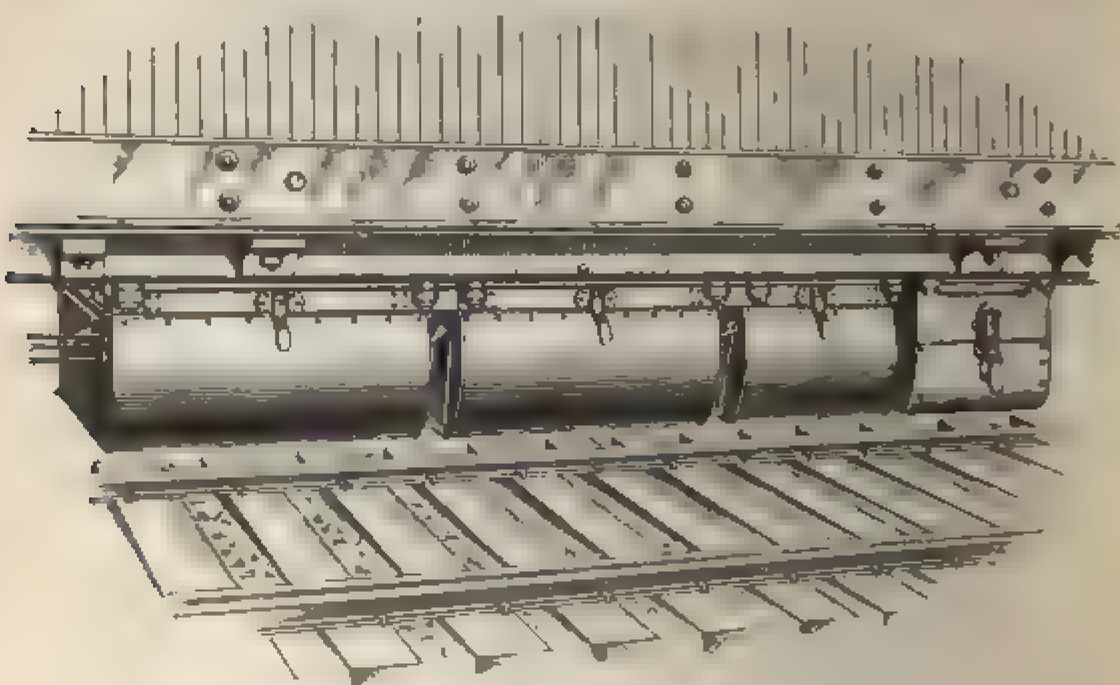


FIG. 10

in the same way as the contactors. A cast-iron rocker *a* is hinged at *b*, and on the ends of the beam are two molded insulation pieces *c*, *c* to which are attached the heavy segments *d*, *d* that carry the main-motor current; segments *e*, *e* are lighter and carry the control current only. Fingers *f*, *f* engage with the heavy segments, and *g*, *g* with the lighter ones. The rocker can be moved through a limited range by means of two solenoids, one of which is shown at *h*; a similar coil is behind *h*, the end of its plunger being seen at *k*. The plungers of the solenoids are connected to the rocker-arm through suitable links, and the movement of the rocker is

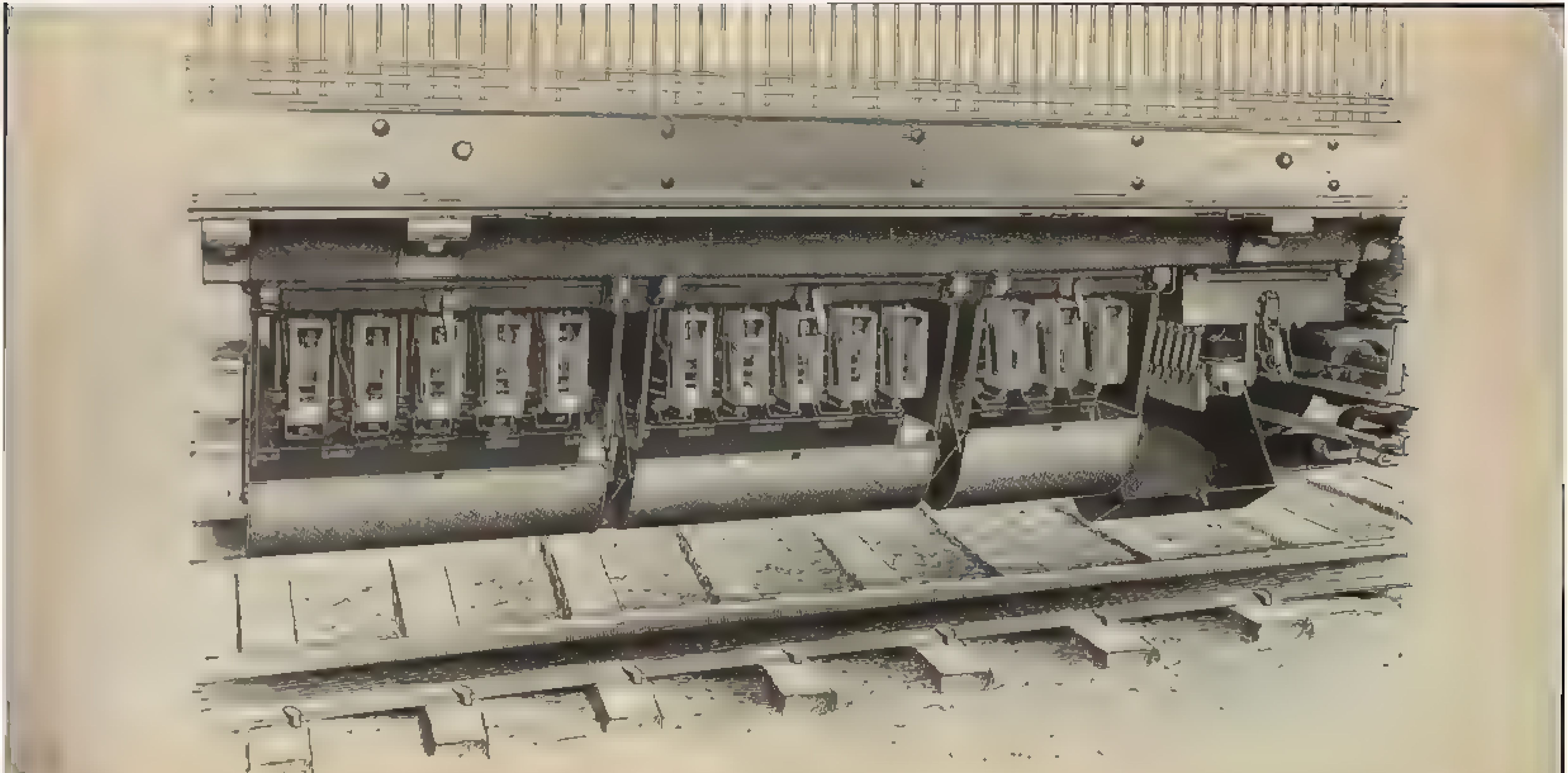


FIG 11

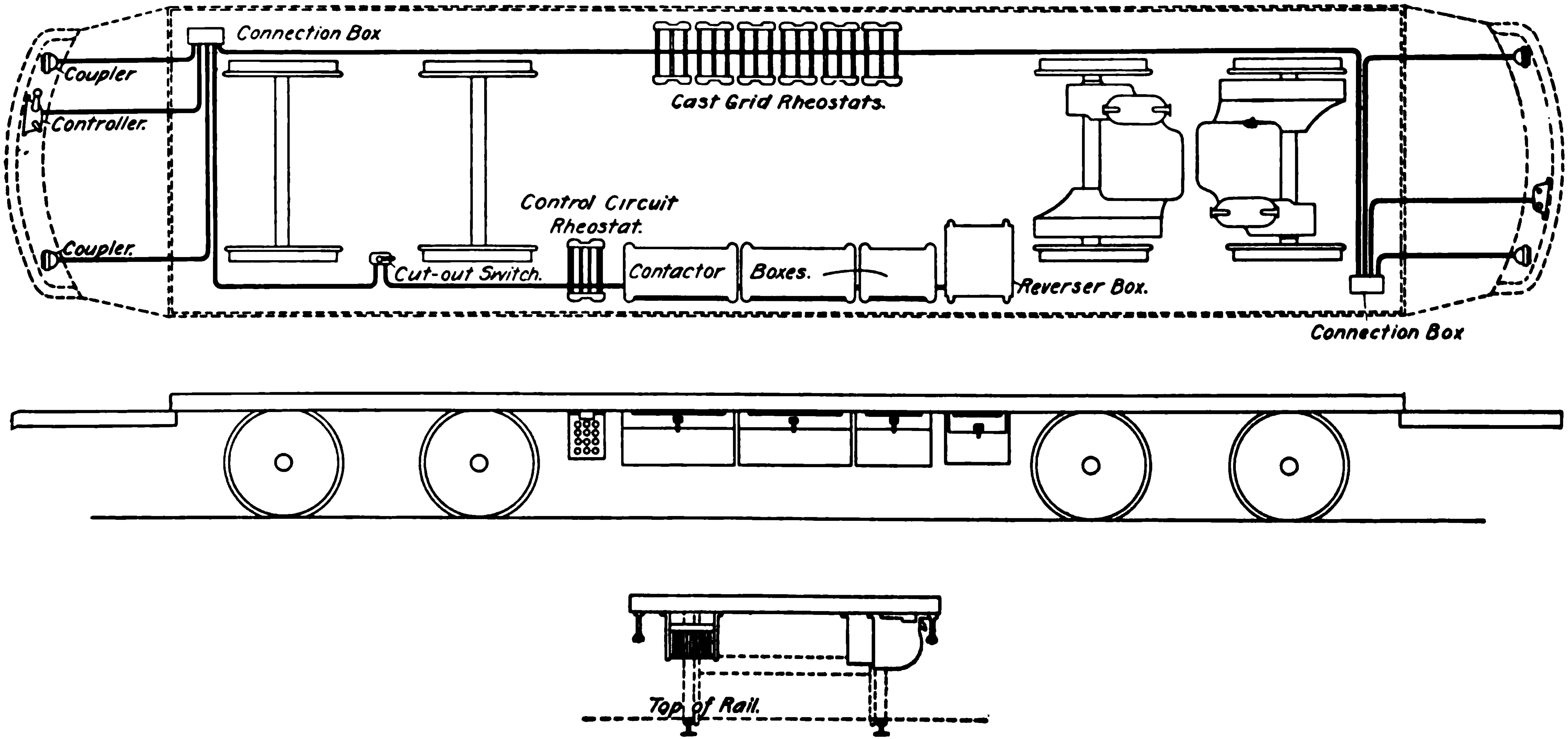

Connection Box
Coupler
Controller.
Coupler.
Cast Grid Rheostats.
Control Circuit
Rheostat.
Cut-out Switch.
Contactor
Boxes.
Reverser Box.
Connection Box
Top of Rail.

Fig. 12

limited by stops. When coil *h* is energized, the rocker occupies the position shown in the figure; but when the other coil is energized, the rocker is thrown over to the other position, the left-hand side being pulled toward the base of the reverser and the other side moving down, thus bringing different sets of contacts under the contact fingers. Suitable interlocks make it impossible for both coils to be energized

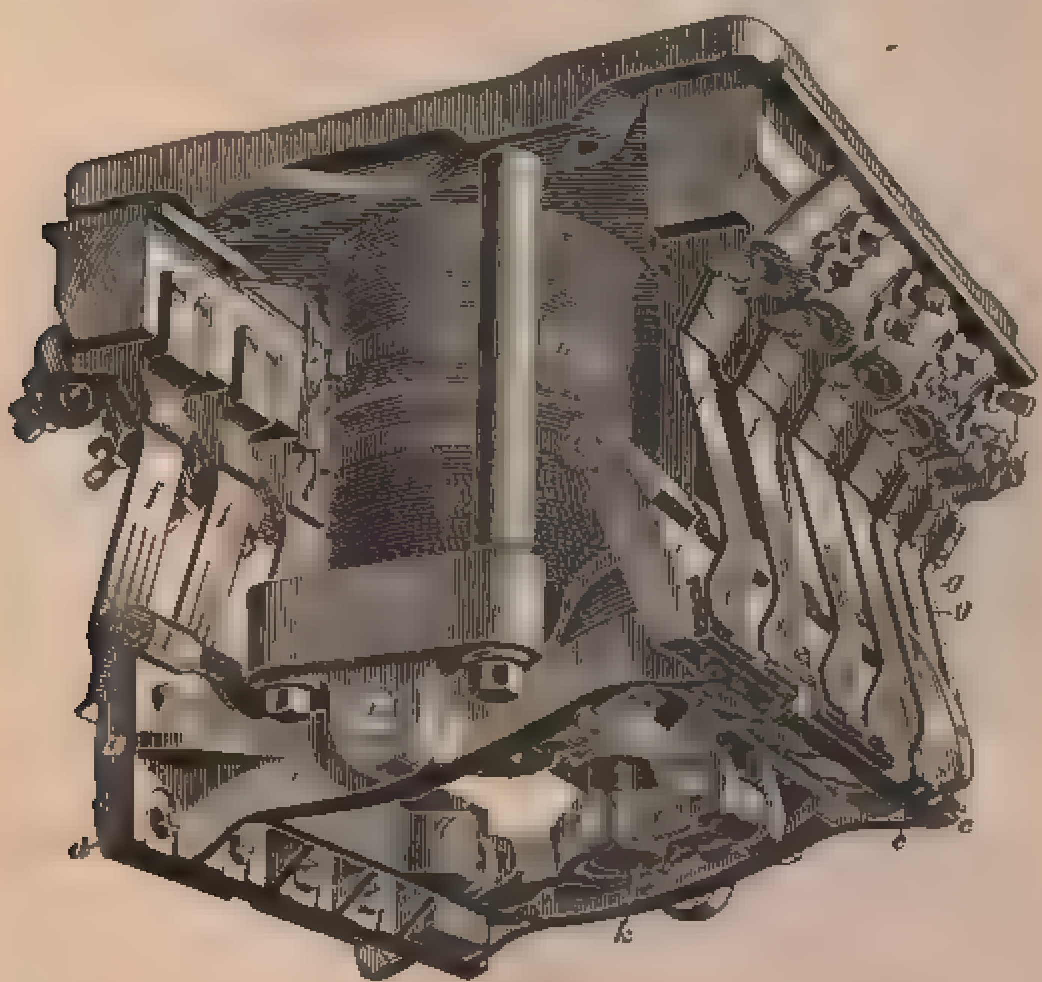


Fig. 13

at once. One position of the rocker corresponds to the forward position of the reverse handle on the master controller, and the other to the reverse position.

**17. Connection Boxes.**—Each car equipped with the type M control is provided with two **connection boxes**, shown at *27*, *27'*, Fig. 2, which are located under the car. Their object is to afford a simple and effective means of connecting corresponding wires of several control cables without the use of permanent splices. Fig. 14 shows the style of box

used. It is made of iron and contains an insulating base *a* on which are mounted clamps *b* for connecting the similar wires of the different control cables. Holes *c* are tapped for 1-inch pipes through which the cables enter, the ends of the wires being soldered to the small terminals *b*, *b*. In Fig. 2, there are four control cables entering the left-hand box and three entering the right-hand box, and in each box the similar wires in each cable are connected together by the clamps. The screwing of cover *d* in place renders the connection box water-tight.

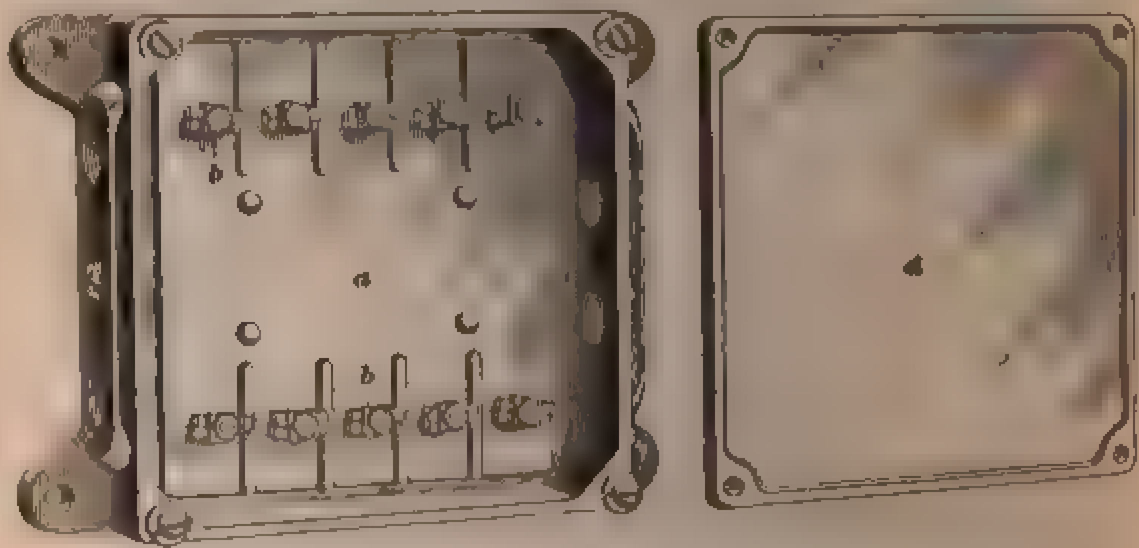


FIG. 14

**18. Coupling Devices.**—All cars that are to be coupled up into multiple unit trains must be provided with means for carrying the train control wires from car to car. If cars unequipped with motors are to be used in connection with motor cars, they must be provided with means for preserving the continuity of the control cable throughout the train. Connections of the control cable from car to car are made by means of couplers consisting of *sockets* placed under each car platform or set into the dash, and a short piece of cable with a plug at each end. The piece of cable with its two plugs is called a *jumper*. Fig. 15 (*a*) shows a jumper consisting of two plugs connected by means of a piece of control cable provided with a rubber covering. Fig. 15 (*b*) shows one of the sockets or receptacles, which is provided with

nine insulated contacts *a* connected to the nine train wires. The contacts are numbered *0* to *8*, inclusive, and the train wires are provided with coverings in different colors or

(*a*)

(*b*)

Fig. 15

combinations of colors, so that there will be no difficulty in getting the wires connected to corresponding terminals at each end of the car. The hinged cover *b* swings down over the front of the socket when it is not in use, thus excluding dirt and water.

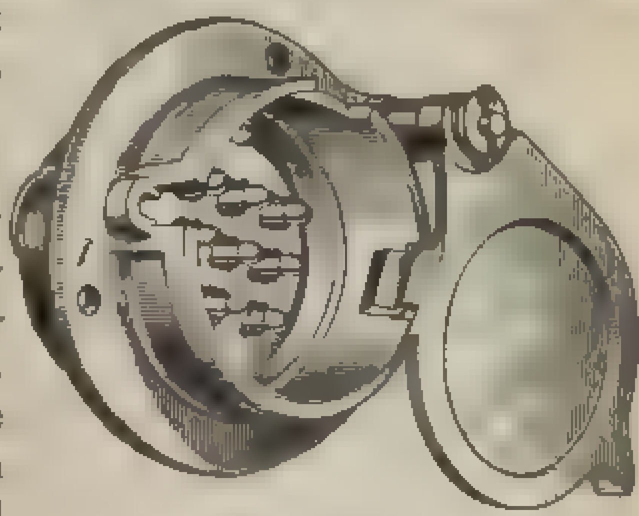


Fig. 16

The removable plugs, shown in Fig. 15 (*a*), are provided with nine receptacles *a'* into which the terminals *a* in the socket fit. The lug *c* slides into the slot *d* shown in (*b*), when the plug is inserted, and unless lug *c* is placed in line with *d*, the plug cannot be put in place; it is thus impossible to put in a plug upside down and get the train wires interconnected wrongly. The coupler sockets are provided with spring catches that hold the plugs in place against any

strains that arise in ordinary use, but if an undue strain is brought on the jumper, as, for example, by a parting of the train, the catches allow the plugs to pull out. It is customary to provide two coupler sockets at each end of the car, one on each side of the center line, as in Figs. 2 and 12; by using two sockets, a car can always be conveniently connected to an abutting car, because, no matter what may be the end-on relation of the cars, two sockets will always be directly opposite each other. Also, when there are two sockets on each end, one is available in case the other becomes defective, so that the double-socket equipment increases the reliability of the outfit. In order to have one socket on each end of a car meet all conditions of service, that socket must be either in the center of the end of the platform, or the single socket on opposite ends must be on opposite sides of the car, as in the case of air-brake couplings. Fig. 16 shows the style of socket used on interurban cars. The socket is set into the dash and secured to it by flange *f*.

**19. Cut-Out Switch.**—The object of the cut-out switch, as used with the type M control, is to provide a means of disconnecting control wires of the devices on the car from the train-line control wires. It is shown at *28*, Fig. 2, and is usually located under a car seat or in the special cab or compartment that is often provided for the control apparatus. The switch consists of a drum with nine contact strips corresponding to the nine wires of the control cable. On each side of the drum is a row of nine contact fingers, one set being connected to the incoming control wires from the connection board and the corresponding fingers of the opposite set connected to the outgoing wires leading to the control coils. When the handle of the switch is at the on-position, the contact strips on the drum connect opposite fingers and thus make the path through the switch continuous. When the handle is thrown to the off-position, the contact strips leave one set of fingers and thus place a break in each of the control wires. This prevents the devices on the car from operating, though it does not interfere in any way with the

operation of the devices on the other cars of the train. If, therefore, the motors or other operating devices on a car become defective, they can at once be cut out of service by means of the cut-out switch.

**20. Control Cables.**—The cables required for the equipment of a car with type M control are shown in Fig. 2. They are named and located as follows: On the front end of the car are located the No. 1 master controller and connection box connected by a short cable called the *No. 1 master controller cable*, another short cable connecting the cut-out switch to the connection box is called the *local control cable*. The small cables running from the connection boards to the coupler sockets are called the *forward-coupler cable* or *rear-coupler cable*, as the case may be. The No. 2 master controller and No. 2 connection board are on the rear end of the car, and the cable running between them, called the *No. 2 master-controller cable*, is interchangeable with a similar cable on the front end. The *train cable* runs between the connection boxes, as shown, and the *local contactor cable* carries the control wires to the several contactors. With the exception of the cable connecting the cut-out switch to the operating coils of the reverser and contactors, the control cables contain nine wires. The main-motor cable consists of three parts, the branch running to the starting rheostat, the branch running to the reverser, and the part connecting to the motors. The relative arrangement of the apparatus may differ considerably from that shown in Fig. 2, because most

FIG. 17

of the appliances have to be placed under the car and their exact position is therefore determined by the location of other appliances, such as air-brake apparatus, brake rigging, etc.

**21. Control-Circuit Rheostat.**—The control-circuit rheostat, Fig. 17, is made up of twelve high-resistance coils completely enclosed in a sheet-iron protecting case. The ends of the coils are brought to the outside of the case and connected to terminals *a*. The operation of the master controller cuts sections of the control rheostat out or in, according as contactor operating coils are cut in or out, thereby maintaining the control current per car approximately constant and preventing any of the contactor coils from being subjected to abnormal pressure.

**22. Motor-Circuit Rheostat.**—In order to prevent a rush of current through the motors at starting and secure a smooth acceleration, a rheostat must be used in the main-motor circuit as with ordinary car equipments. The rheostat is of the cast grid type and is made up of a number of units, as shown in Fig. 2. The resistance is the same in its general construction as that used for ordinary cars, so that further description is unnecessary.

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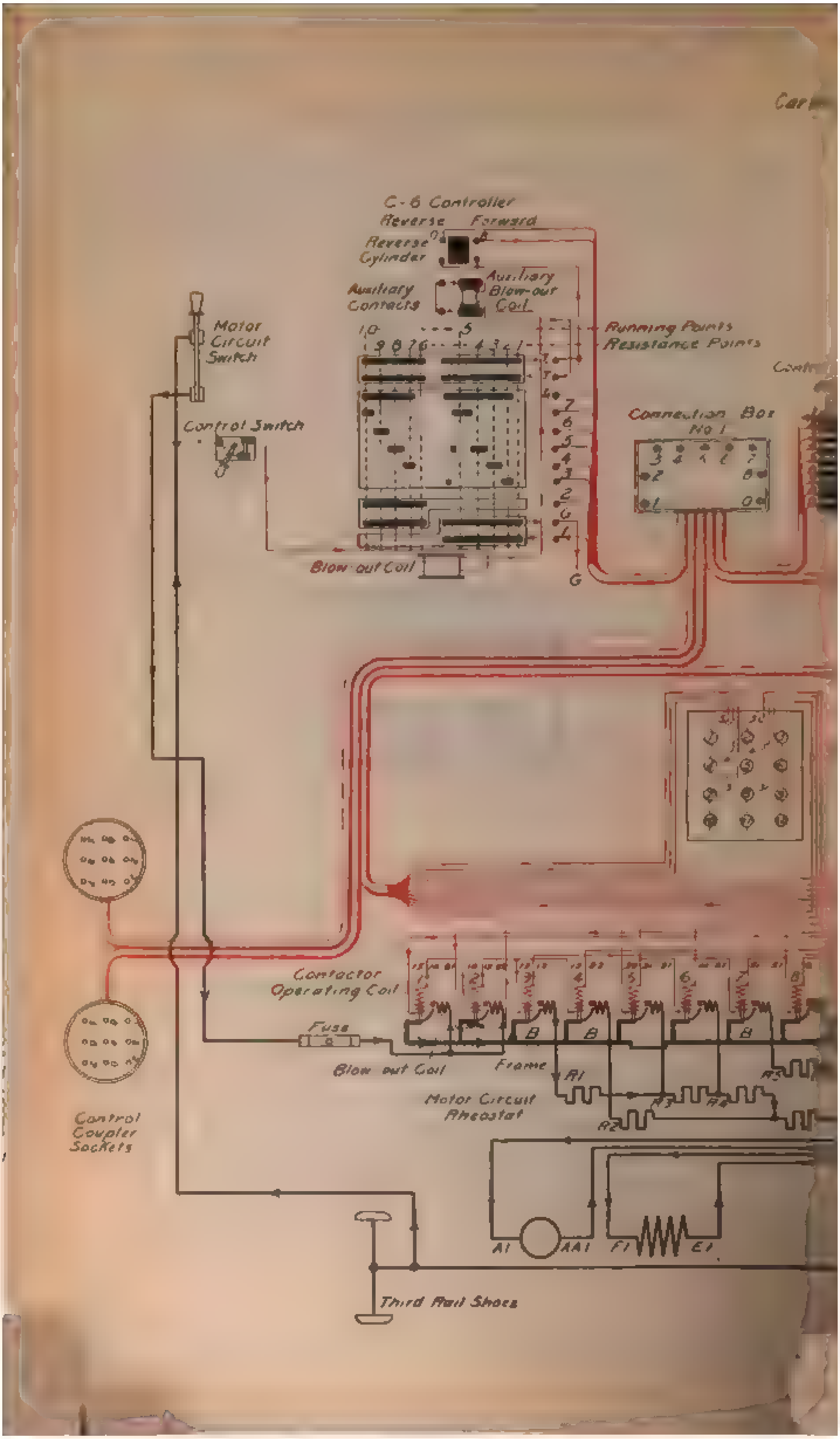
### WIRING DIAGRAM FOR TYPE M CONTROL

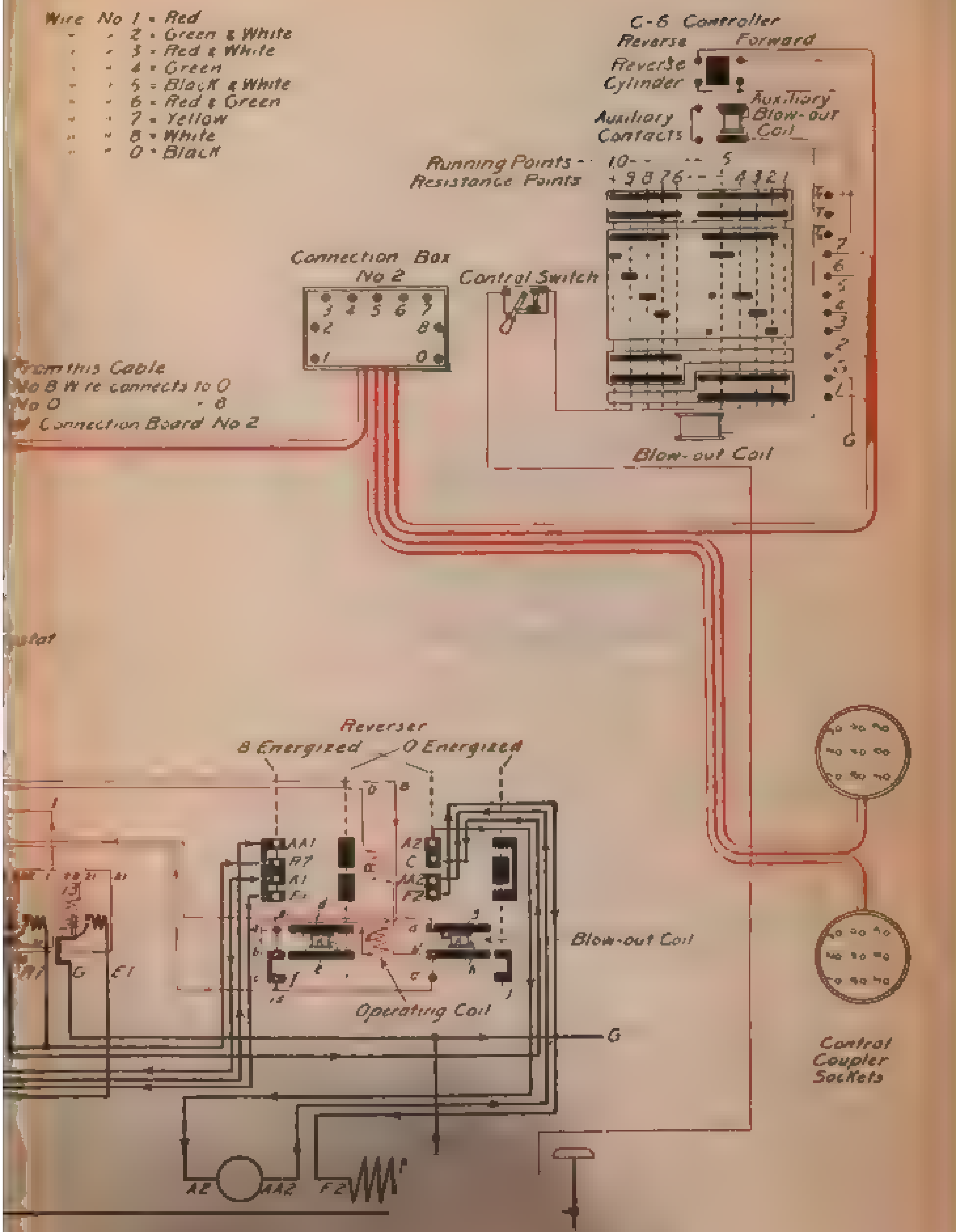
**23. General Description.**—Fig. 18 is a general diagram of the wiring for two C6 master controllers operating two motors, the equipment corresponding to that shown in Fig. 2. The control-circuit wires are printed in red and the operating-circuit wires in black, in order that each may be more readily distinguished. The various operating devices are printed in black irrespective of whether they belong to the operating circuit or to the motor circuit.

At the top of the master controller is shown the small reverse drum with the two control wires *0*, *8* connected to its contact fingers. Immediately below the reverse drum is the safety switch, with the auxiliary blow-out coil connected between the two fixed contacts of the switch. Below this is



C-6 Controller
Reverse
Forward
Reverse Cylinder
Auxiliary Contacts
Auxiliary Blow-out Coil
Motor Circuit Switch
Running Points
Resistance Points
Control Switch
Connection Box No 1
Blow-out Coil
Contactor Operating Coil
Fuse
Blow-out Coil
Frame
Motor Circuit Rheostat
Control Coupler Sockets
Third Rail Shoes

-General Electric
-rol



the operating cylinder made up of four castings; the black strips show the development of the contact segments, and all the segments on the same casting are, of course, connected electrically. Below the operating cylinder is the blow-out coil for suppressing the arcs at the contact fingers, represented by the vertical row of dots at the right. The main contacts on the reverser are shown by the heavy black bands engaged in pairs by the reverser main-circuit fingers marked *AA1*, *R7*, *A1*, *F1*, *A2*, *C*, *AA2*, *F2*. In the diagram, the operating coil to which wire *8* leads is responsible for the position in which the contacts are shown. Introduction of current to the operating coil connected to reverse wire *0* will cause the reverser contacts to shift bodily to the left. Fingers *a*, *b*, *c*, *a'*, *b'*, *c'* and narrow contacts *d*, *e*, *f*, *g*, *h*, *i* have to do with the control circuit. Small magnetic blow-out coils are shown at *k k*. The object of these interlock contacts and fingers on the reverser is to insure that no motor current will flow through the reverser unless it is in an operating position; i. e., unless the main reverser contacts are resting on their segments, and also that the reverser occupies the position to give the car the required direction of motion. For example, if the train is required to move forward, and the reverse switch of the master controller is set to the forward position, it may happen that, through previous use, the reversers on some of the cars do not occupy the position corresponding to the train movement, and these auxiliary contacts insure that the reverser will occupy the correct position before the main current is allowed to flow, otherwise certain contactors that are necessary to admit current to the motor circuit cannot operate and the car cannot take current. This will be seen when the operation of the devices is considered.

**24. Operation on First Notch of Master Controller.** It is assumed that the master-controller reverse cylinder is moved to the forward position and that the power handle is moved to the first position, as indicated by the vertical dotted line *1* on the development of the operating cylinder. The car or train is assumed to be operated from the left-hand

controller. As soon as the operating handle is moved from the off-position, the safety switch closes, since the dead-man's knob is supposed to be pressed down. The path of the control current is then as follows: Control-circuit switch–fuse–main blow-out coil–auxiliary blow-out coil–safety switch–finger *T*–finger $T_1$–finger *8* by way of reverse cylinder–*8* on connection box No. *1*–post *8* on cut-out switch–reverse operating coil *8*–reverser control finger *b*–contact segment *f*–finger *c*–*15*–*15*–operating coil of contactor *1*–*14*–*14*–operating coil of contactor *2*–*13*–*13*–operating coil of contactor *3*–*12*–*12*–operating coil of contactor *11*–*11*–*11*–interlock contact *38*–interlock contact *39*–*1*–*1*–fuse *1*–cut-out switch *1*–connection-box terminal *1*–operating-cylinder finger *1*–ground finger *G*. On the first point, therefore, contactors *1*, *2*, *3*, and *11* are operated, and the reverser is at the forward position, shown in the figure. The path of the motor current corresponding to this combination will be: Motor-circuit switch–main fuse–$<\begin{matrix}\text{contactor } 1\\ \text{contactor } 2\end{matrix}>$–frame *B*–contactor *3*–*R1*–*R3*–*R4*–*R7*–*R7* (on reverser)–*A1*–*A1*–*AA1*–*AA1*–*F1*–*F1*–*E1*–*E1* (on contactor *11*)–*C*–*C* (on reverser)–*A2*–*A2*–*AA2*–*AA2* (on reverser)–*F2*–*F2*–*E2*–ground. The arrowheads in Fig. 18 show the paths of the control current and main-motor current when the master controller is on the first notch.

In tracing the above control circuit, it was assumed that the reverser already occupied the position shown in the figure and corresponding to that assumed when coil *8* is energized. Suppose, however, that the rocker had, on account of previous use or for any other reason, occupied the opposite position, so that the small interlock fingers on the reverser rested on segments *d*, *e*, and *j* instead of *g*, *h*, and *f*. The current entering at *8* would then take the path *8*–through operating coil *8*–finger *b*–segment *e*–blowout coil *k*–segment *d*–contact finger *a*–*81*–*81*–interlock on contactor *2*–*82*–*82*–fuse–ground. There can be no current flow in the motor circuit unless contactors *1* and *2*, called *line contactors*, are closed. Current is introduced to the

reverser operating coil only when master-controller fingers $T$ and $T_1$ make contact with cylinder casting $A$. If on moving the operating handle to the first notch, the reverser happens to rest in a position corresponding to the existing position of the reversing handle, current takes the path already outlined and closes the line contactors so that motor current can flow. Should the reverse rest in the wrong position, however, control finger $c$ is not in contact with anything and the line contactors cannot close. Reverser current does, however, take the path leading through the interlock on contactor *2*, thereby throwing the reverser to the correct position in which the line-contactor operating coils can get current. Simultaneously with the operation of the line contactors, the interlock switch on contactor *2* of course opens, thereby interrupting in a second place the circuit used for throwing the reverser to correct position and which the reverser itself interrupted at the instant of operation. Blow-out coils $k$, $k$ suppress all arcing that tends to follow the interruption of the control current. Contactors *1*, *2* are connected in parallel so as to reduce the current handled by each, because these contactors correspond to the trolley fingers of an ordinary controller, and the service imposed on them is more severe than on the others. Contactors *9*, *10* are connected in a similar manner.

**25. Operation on Last Series Notch.**—As the drum is turned to positions *2*, *3*, and *4*, contactors *5*, *6*, and *7* are added to those already in operation, as can be seen by tracing out the control circuit. The result is to reduce the resistance in series with the motors. On the fifth position, which is the last series notch and one of the running notches, all of the resistance is cut out. The path of the operating current is as follows, starting from finger $T$ on the master controller: $T$–$T_1$–$T_2$–finger *7*–connection-box terminal *7*–cut-out contact *7*–terminal on contactor *10*–*71*–*71*–contactor *9*–*6*–*6*–contactor *8*–*51*–*51*–contactor *7*–*41*–[illegible] contactor *6*–*31*–*31*–contactor *5*–*3*[illegible] of the reverser current remains a[illegible]ary to trace it out.

The motor current takes the path: Motor-circuit switch–fuse–$\left\{\begin{matrix}\text{contactor } \mathit{1}\\ \text{contactor } \mathit{2}\end{matrix}\right\}$–frame *B B*–$\left\{\begin{matrix}\text{contactor } \mathit{9}\\ \text{contactor } \mathit{10}\end{matrix}\right\}$–*R7–R7–A1–AA1*, etc.–ground. All the resistance is cut out and the two motors are in series.

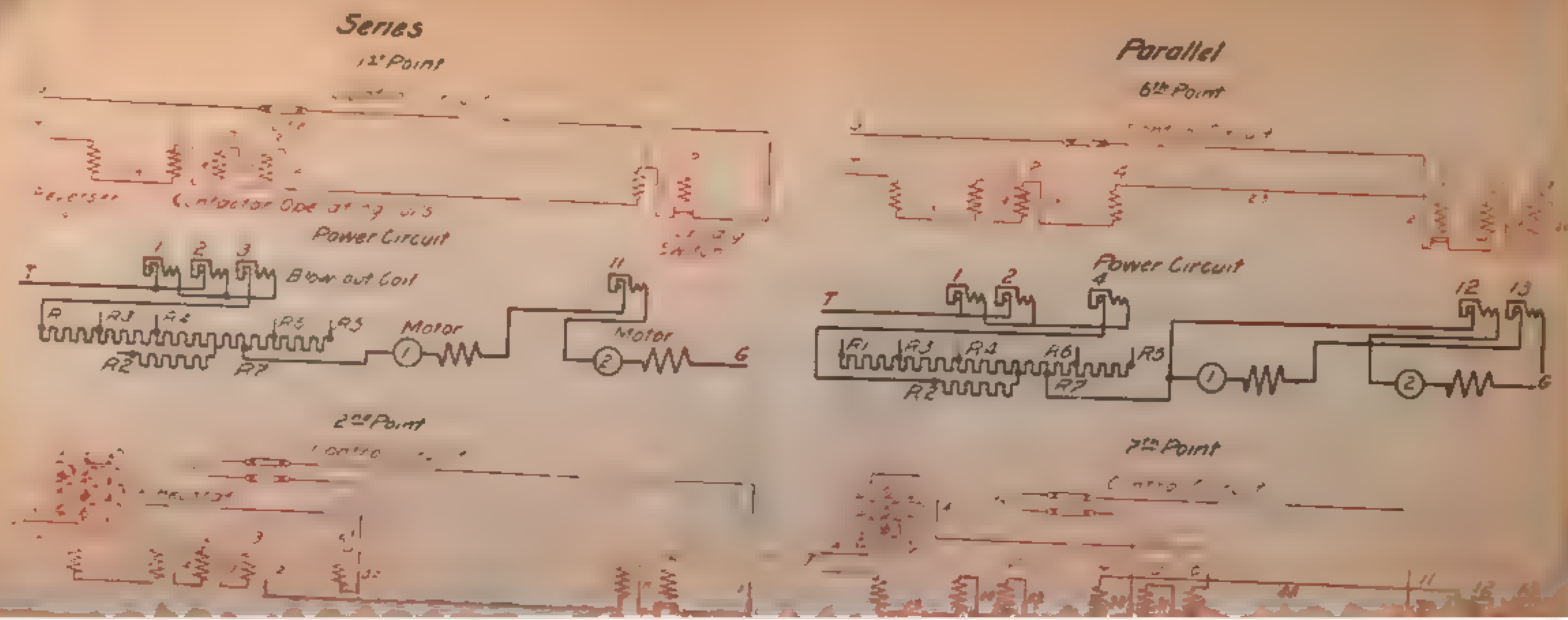
**26. Operation on First Parallel Notch.**—When the controller is on position *6*; i. e., the first parallel notch, the operating current may be traced from finger *T* as follows: $T$–$T_1$–reverse cylinder–*8–8* on connection board–*8* on cut-out switch–coil *8* on reverser–*b–c–15–15*–contactor *1–14–14*–contactor *2–13–13*–contactor *4–23–23*–contactor *12–22–22*–contactor *13–21–21*–interlock *37–36–2*–fuse *2–2* on cut-out–*2* on connection-box–finger *2* on controller–ground. This operates the reverser, or rather keeps the reverser in the position that it already had on the series notches, and operates contactors *1*, *2*, *4*, *12*, and *13*.

The path of the motor current is then as follows: Motor-circuit switch–fuse–$\left\{\begin{matrix}\text{contactor } \mathit{1}\\ \text{contactor } \mathit{2}\end{matrix}\right\}$–*B–B*–contactor *4–R2–R7*–$\left\{\begin{matrix}\mathit{R7}\text{ (on reverser)}\text{–}\mathit{A1\text{–}A1\text{–}AA1\text{–}AA1\text{–}F1\text{–}F1\text{–}E1}\text{–}\\ \mathit{R7}\text{ (contactor } \mathit{12}\text{)–contactor–}\end{matrix}\right.$

$\left.\begin{matrix}\text{contactor } \mathit{13}\text{———————————}\\ \mathit{12\text{–}C\text{–}C\text{–}A2\text{–}A2\text{–}AA2\text{–}AA2\text{–}F2\text{–}F2\text{–}E2}\end{matrix}\right\}$–ground.

The motors are therefore in parallel with two sections of the resistance in series with the circuit.

**27. Operation on Last Parallel Notch.**—On position *7*, contactors *5* and *6* operate and reduce the resistance in the circuit by placing a resistance section in parallel with one of the sections previously inserted. On the eighth position, contactor *7* is picked up and resistance sections *R5–R6–R7* are placed in parallel with those already in use. On the ninth position, contactor *8* is picked up and resistance sections *R5–R6* short-circuited. On the last parallel notch, contactors *9*, *10* are picked up, thus establishing a direct connection between *B B* and the wire *R7 R7* running to the reverser and thereby cutting out all resistance. On the parallel notches, the resistance in series with the motors is, in



Series
1st Point
Reverser
Contactor Operating Coils
Power Circuit
Blow out Coil
Motor
Motor
2nd Point
Parallel
6th Point
Power Circuit
7th Point

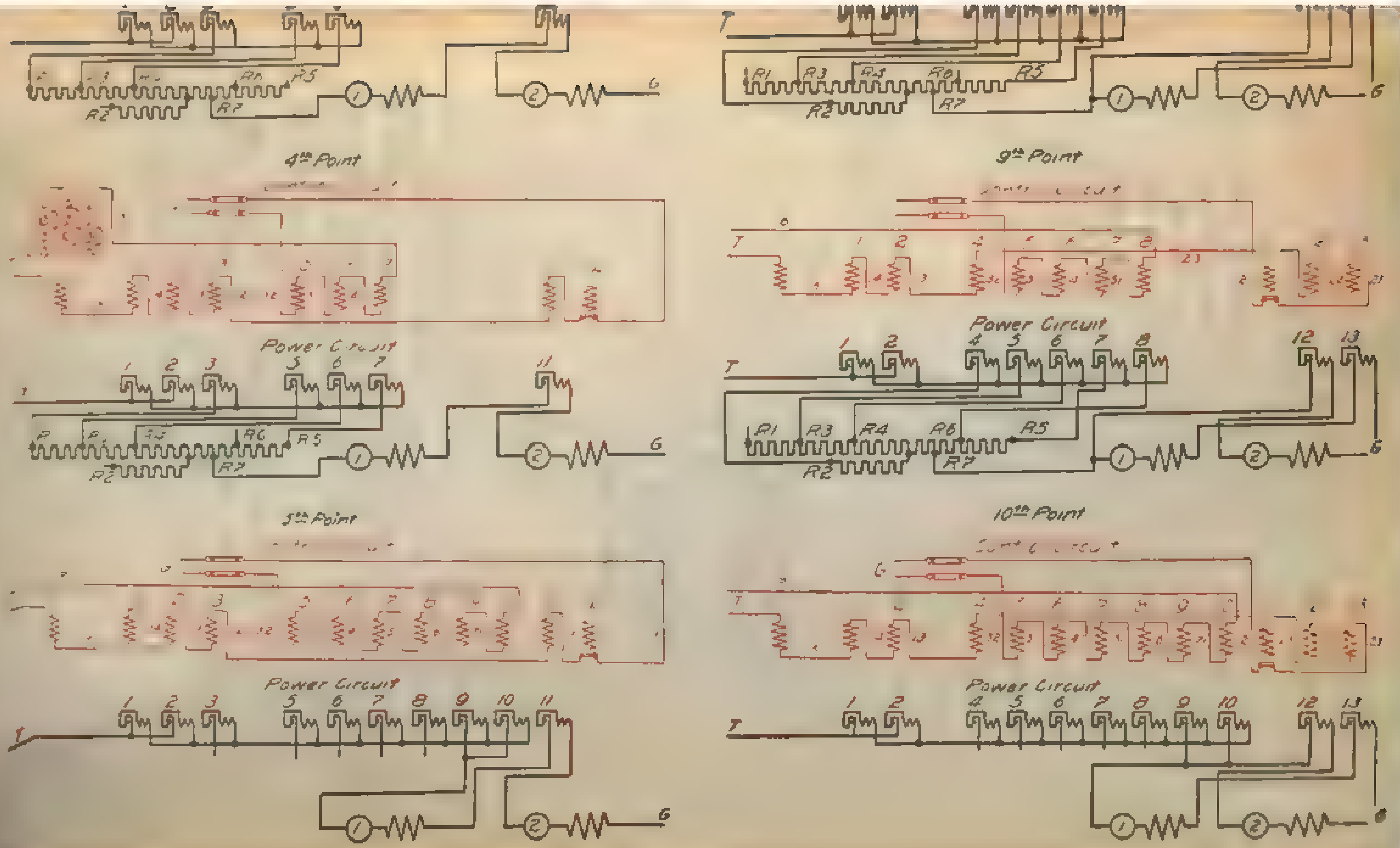

4th Point
Power Circuit
5th Point
Power Circuit
9th Point
Power Circuit
10th Point
Power Circuit

Fig. 19

some cases, decreased by connecting sections in parallel rather than by cutting out existing sections. The advantage of this method is that, as the resistance is reduced, its carrying capacity is increased and it is better able to handle the heavy current taken by the car on the parallel notches.

As far as the final effect on the motors is concerned, the combinations effected by the movement of the master controller are practically the same as effected by an ordinary series-parallel controller, though the master controller itself

TABLE I

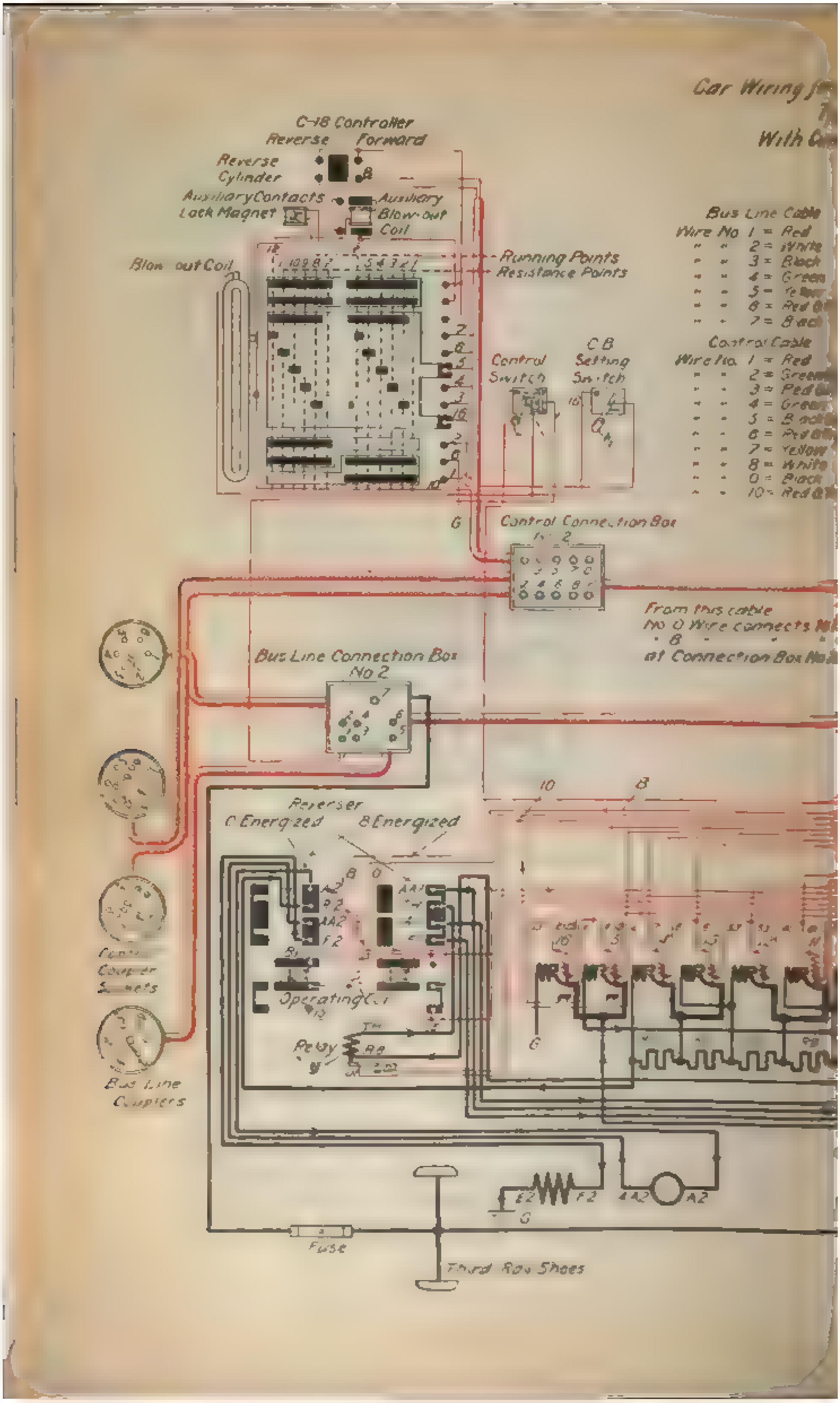
| Number of Notch | Contactors in Operation | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 2 | 3 | | | | | | | | 11 | | |
| 2 | 1 | 2 | 3 | | 5 | | | | | | 11 | | |
| 3 | 1 | 2 | 3 | | 5 | 6 | | | | | 11 | | |
| 4 | 1 | 2 | 3 | | 5 | 6 | 7 | | | | 11 | | |
| 5 | 1 | 2 | 3 | | 5 | 6 | 7 | 8 | 9 | 10 | 11 | | |
| 6 | 1 | 2 | | 4 | | | | | | | | 12 | 13 |
| 7 | 1 | 2 | | 4 | 5 | 6 | | | | | | 12 | 13 |
| 8 | 1 | 2 | | 4 | 5 | 6 | 7 | | | | | 12 | 13 |
| 9 | 1 | 2 | | 4 | 5 | 6 | 7 | | 8 | | | 12 | 13 |
| 10 | 1 | 2 | | 4 | 5 | 6 | 7 | 8 | 9 | 10 | | 12 | 13 |

is not connected with the motors. In Fig. 18, the connections have been explained by referring to the operation of devices on one car only. Where a number of cars are coupled together, the whole train control line becomes energized and the devices on all cars operate synchronously with those on the operating car.

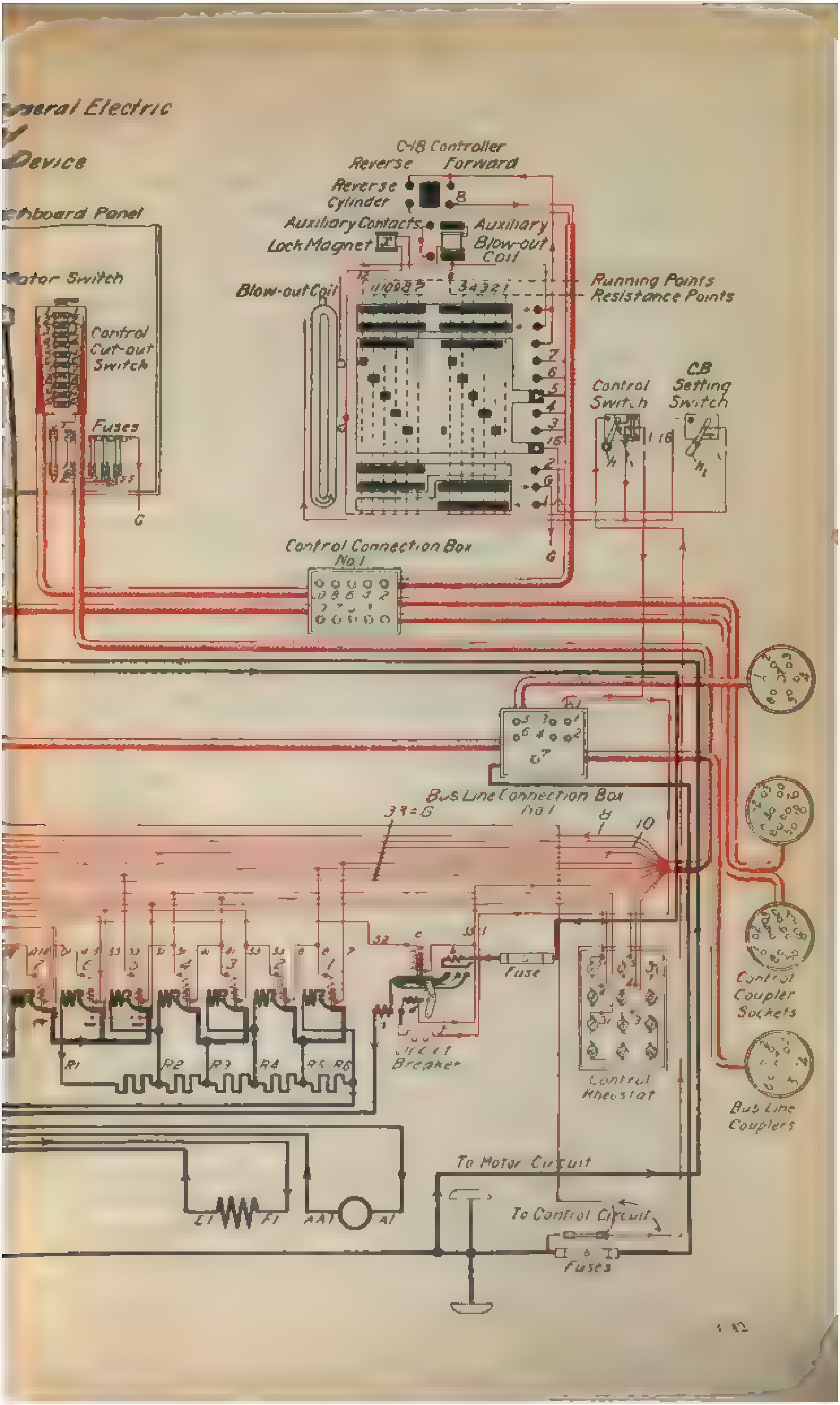
**28.** Fig. 19 is a diagrammatic sketch of the control-circuit and motor-circuit combinations existing on all points of the C6 master controller. Table I shows the contactors in operation on each point.

## WIRING DIAGRAM OF TYPE M CONTROL WITH CURRENT-LIMITING DEVICE

**29. General Description.**—Fig. 20 is a diagram of connections for type M control with C18 controllers. The chief differences between this diagram and that shown in Fig. 18 lie in the number and arrangement of the contactors and the addition of an automatic device that prevents the car from taking more than a predetermined current at starting. The contactors are of the type already described, those of approximately the same potential being grouped together on a common base, to economize space and simplify connections. In order to insure the fastest possible acceleration without slipping of the wheels, the following arrangement is provided: The controller cylinder instead of being positively driven by the shaft to which the operating handle is attached, is connected thereto by means of a spring; a magnetically operated lock prevents the cylinder from following the movement of the operating handle so long as the current taken by the motors exceeds the allowable amount. Thus, if the motorman were to throw the operating handle around rapidly to, say, the full series position before the motors had time to gain headway, the train would take an excessive current if no automatic throttle or current-limiting device were provided, and wheel slippage would occur. In this controller, the power drum does not at once follow the movements of the handle; a rapid movement of the handle simply places the spring between the handle and shaft under tension, and the latter cannot move until it is unlocked. When the current falls to an amount sufficient to unlock the shaft, the spring moves the cylinder forward with the result that it follows the movement of the handle step by step until it reaches the position occupied by the handle. If the motorman moved the power handle so slowly that the starting current never exceeded the allowable amount, the drum would not be locked and it would follow the movements of the handle as in an ordinary controller. In practice, however, where this type of controller is used, the motorman



Car Wiring f
With C
C-18 Controller
Reverse
Forward
Reverse Cylinder
Auxiliary Contacts
Lock Magnet
Auxiliary Blow-out Coil
Running Points
Resistance Points
Blow-out Coil
Bus Line Cable
Wire No. 1 = Red
2 = White
3 = Black
4 = Green
Control Cable
Wire No. 1 = Red
7 = Yellow
8 = White
Control Switch
C B Setting Switch
Control Connection Box No. 2
From this cable
No. 0 Wire connects
at Connection Box No.
Bus Line Connection Box No. 2
Reverser
0 Energized
8 Energized
Operating Coil
Relay
Control Coupler Sockets
Bus Line Couplers
Fuse
Third Rail Shoes



...neral Electric
...Device
...chboard Panel
...otor Switch
Control Cut-out Switch
Fuses
C-18 Controller
Reverse
Forward
Reverse Cylinder
Auxiliary Contacts
Auxiliary Blow-out Coil
Lock Magnet
Blow-out Coil
Running Points
Resistance Points
Control Switch
CB Setting Switch
Control Connection Box No. 1
Bus Line Connection Box No. 1
Fuse
Circuit Breaker
Control Rheostat
Control Coupler Sockets
Bus Line Couplers
To Motor Circuit
To Control Circuit
Fuses

throws the handle around to the running position and the controller notches up as fast as the locking device will permit.

**30.** In Fig. 20, the locking device is controlled by the electromagnet *x* on the master controller and the current in this magnet is controlled by the relay shown at *y*. The relay consists of a coil connected in series with one of the motors so that it carries the main current. If the current exceeds the allowable amount, the relay operates and connects magnet *x* in shunt with one or the other of the reverser operating coils, according to which is in use, thus locking the controller. When the current drops below the limit, the current through *y* decreases until the relay contacts are opened and the magnet in the controller unlocks the cylinder and allows it to move under the influence of the spring connected to the main shaft.

It will not be necessary to trace out the paths of the current on all the notches in Fig. 20, since this can be done from the explanation given in connection with Fig. 18. The contactors are arranged differently and their sequence of operation differs from that in Fig. 18, but the principle of operation is the same. On the first position of the master controller, the control-current path is indicated by the red arrowheads and the main-current path by the black arrowheads. The two bus-line connection boxes, the cable connecting them, and the extra pairs of couplers on each end of the car, have to do with an extra train line provided for several purposes. One object is to enable any current-operated device to get its current either from the car on which it is located or from some other car in the train. To illustrate: when either control-switch handle *h* is thrown to the dotted position, the dependent master controller can take current either from the trolley direct or from the bus-line connection-box trolley terminal 7, which is connected to the contact shoes of all cars. This is an important feature, because where a master controller can draw current only from the contact shoes of the car on which it is located, should those shoes happen to rest on ice or be off the rail entirely,

it would be necessary to go to another car in order to start the train.

**31.** Another feature of this control is the automatic main-current circuit-breaker and the facilities for setting it before starting or resetting it after operation. The breaker is located to the right of the contactors in Fig. 20. Here *a* is the operating coil and *b* the blow-out coil; both carry the main current, the circuit-breaker being the first device through which the main current passes after leaving the motor switch. By means of setting coil *c*, the circuit-breaker can be set by moving handle $h_1$ of either circuit-breaker setting switch to the dotted position. The circuit-breaker can be closed by operation of the setting switch only when the accompanying master controller is at off-position, because in all other positions fingers *5* and *16*, which are part of the setting circuit, make no contact. When switch $h_1$ is closed, the path of the current through setting coil *c* is as follows, starting from point *16* at setting switch: *16*–setting switch finger *16* on controller–finger *5*–cut-out switch–*5* on control rheostat–*2*–*1*–*51*–*51*–interlock on contactor *10*–interlock on contactor *8*–interlock on contactor *7*–*52*–setting coil *c*–*55*–*55*–fuse–ground. If contactors *7*, *8*, or *10* are closed, the circuit-breaker cannot be set and it is therefore impossible to set the breaker while the main-motor current is on. Setting coil *c* moves the circuit-breaker parts over to where armature *e* on the togglejoint comes within the range of holding coil *d*, which is steadily energized from the bus-line connection box through resistance *f*. Coil *d* holds the breaker closed after the circuit-breaker setting switch has been moved to off-position or after the master controller has been moved to an operating position. As long as the circuit that energizes holding-magnet *d* is closed, the circuit-breaker will remain closed. Excessive current in the motor circuit, however, will cause operating coil *a* to attract its armature composing part of the holding-coil circuit, which is thereby opened and the breaker thrown into operation.

TABLE II

| Positions | Contactors in Action | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | 6 | 7 | | 9 | | | | | | 15 |
| 2 | | | | | 5 | 6 | 7 | | 9 | 10 | | | | | 15 |
| 3 | | | | 4 | 5 | 6 | 7 | | 9 | 10 | 11 | | | | 15 |
| 4 | | | 3 | 4 | 5 | 6 | 7 | | 9 | 10 | 11 | 12 | | | 15 |
| 5 | | 2 | 3 | 4 | 5 | 6 | 7 | | 9 | 10 | 11 | 12 | 13 | | 15 |
| 6 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| 7 | | | | | | 6 | 7 | 8 | 9 | | | | | | 16 |
| 8 | | | | | 5 | 6 | 7 | 8 | 9 | 10 | | | | | 16 |
| 9 | | | | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | | | | 16 |
| 10 | | | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | | | 16 |
| 11 | | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | | 16 |
| 12 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 16 |

**32.** Table II shows the contactors in operation on the positions of the C18 controller. The plan of wiring shown in Fig. 18 is the one generally used for ordinary multiple-unit equipments; the arrangement in Fig. 20, which is somewhat more complicated and includes the auxiliary features just explained, is used in places where the traffic is heavy and where the requirements are unusually exacting, as, for example, on the New York Subway.

# WESTINGHOUSE UNIT-SWITCH CONTROL

## INTRODUCTION

**33.** The **Westinghouse unit-switch system** of train control differs considerably from the type M system already described, but the difference is more in the details of appliances than in the results obtained by their operation. Excepting the master controller, all circuit-making and circuit-breaking devices of the unit-switch equipment are operated by compressed air controlled by electrically operated valves, of which the time and order of operations depend on circuit combinations established by the master controller. The main controller consists of thirteen individual *unit switches* grouped radially so as to occupy a minimum amount of space. The main controller and all other devices, except the master controller and the brake valve, are located under the car in suitable protecting housings, easily opened for inspection. The train line consists of seven wires terminating in sockets and continued from car to car by flexible jumpers, the plugs or terminals of which engage the sockets of abutting cars.

The train line and all operating devices dependent on it are energized through the master controller by a storage-battery current supplied at a pressure of about 15 volts. The battery consists of fourteen cells arranged in two sets having seven cells, in series, in each set. When one set is in service, the other is being charged through the car-lamp circuit, double-throw switches being provided to make the necessary changes for charging and discharging. The use of an independent source of operating current renders operation practicable under the especially trying conditions of service due to a film of ice on the trolley wire or contact rail or in case the power goes off the line; it is also probable that the

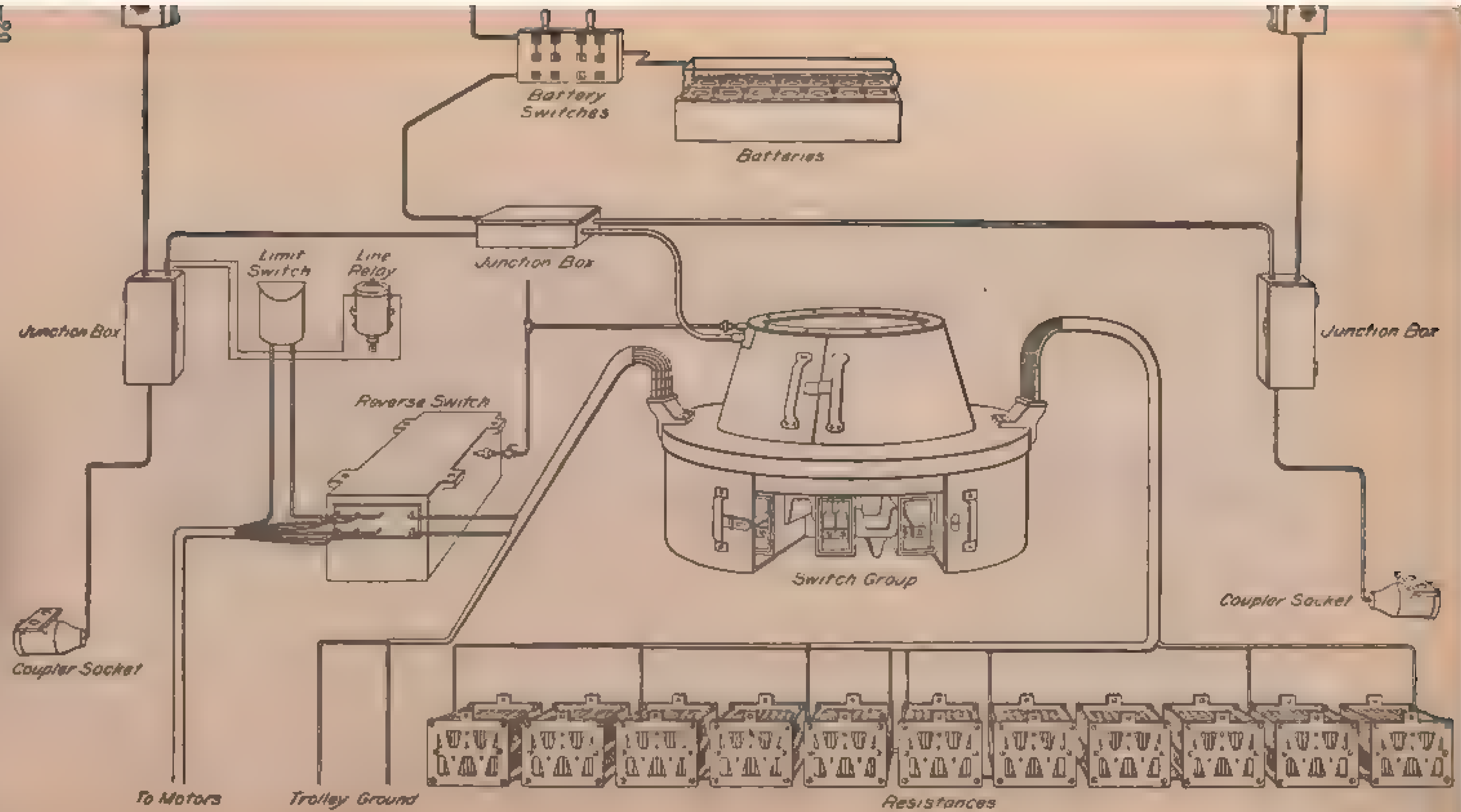
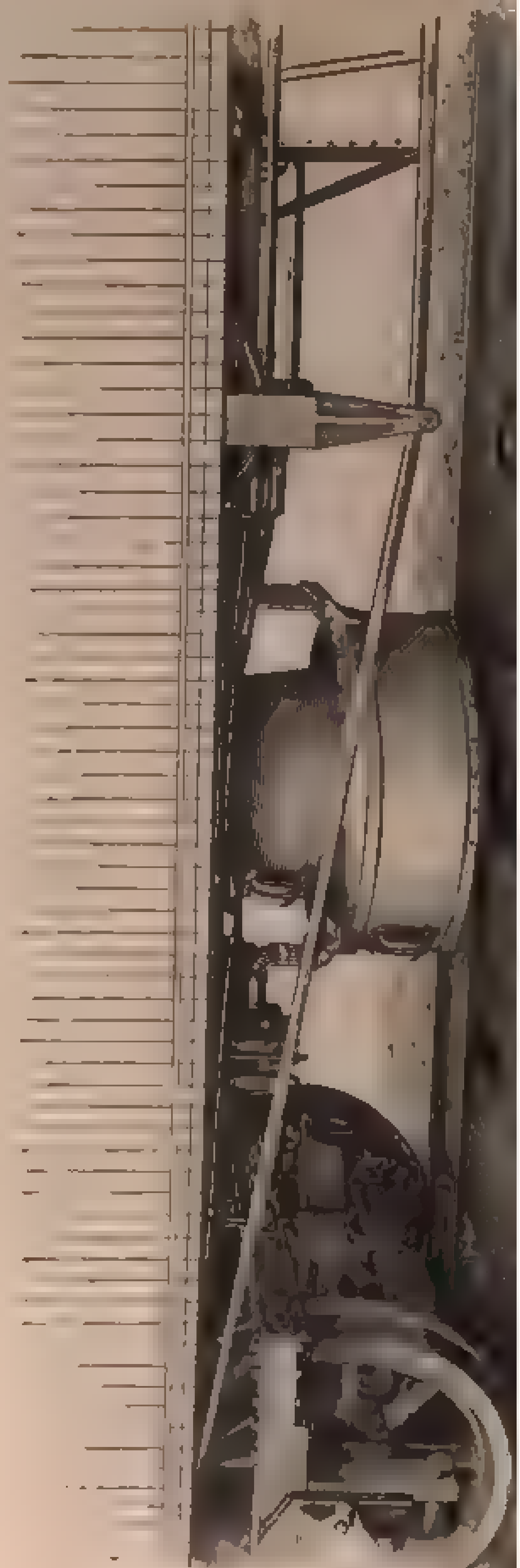

Battery
Switches
Batteries
Junction Box
Limit
Switch
Line
Relay
Junction Box
Junction Box
Reverse Switch
Switch Group
Coupler Socket
Coupler Socket
To Motors
Trolley Ground
Resistances

FIG 21



control circuits are not nearly so likely to become disordered by lightning discharges. The low voltage used in the control circuits considerably simplifies the problem of insulating the control wires and securing durable coupling devices.

**34.** A unit-switch control equipment comprises the following devices: Unit-switch group, master controllers, motor cut-out switches, resistances, storage battery, reverse switch, train line, limit and line relay switches, air connections, and line switches, if required. In considering any device, an understanding of it will, in each case, be made easier by locating the device in Fig. 37, in which the connections are indicated. Fig. 21 shows an assembly of the unit-switch equipment.

## CONTROL DEVICES

### UNIT, OR AIR, SWITCHES

**35.** Fig. 22 shows the location under a car of the **unit-switch group** constituting the main controller. Fig. 23 shows the device with the housing removed, and Fig. 24 is a section through the center of the group shown in Fig. 23; from this drawing the construction of a unit switch and the mechanism for operating it can be understood. The controller consists of thirteen switches *a*, *a*, Figs. 23 and 24, arranged radially around a blow-out coil *b* that is common to all. (One of the unit switches is shown more in detail at the left of Fig. 24.) The fixed contact of the switch is shown at *a′*; the movable one at *b′* is on the end of arm *c*, which has a slight movement around pin *d*. Arm *c*, as a whole, is pivoted at *e* and is moved through rod *f* by piston *g* operating in cylinder *h*. Any arcing between contacts *a′* and *b′* takes place in chamber *i*. The radial arms *j* and *k* form poles projecting from the top and bottom of the blow-out coil. A strong magnetic field is therefore set up across the region in which the switch contacts are located and the arc is blown out radially. The object of giving the contact arm *c* limited movement around *d* as a center in

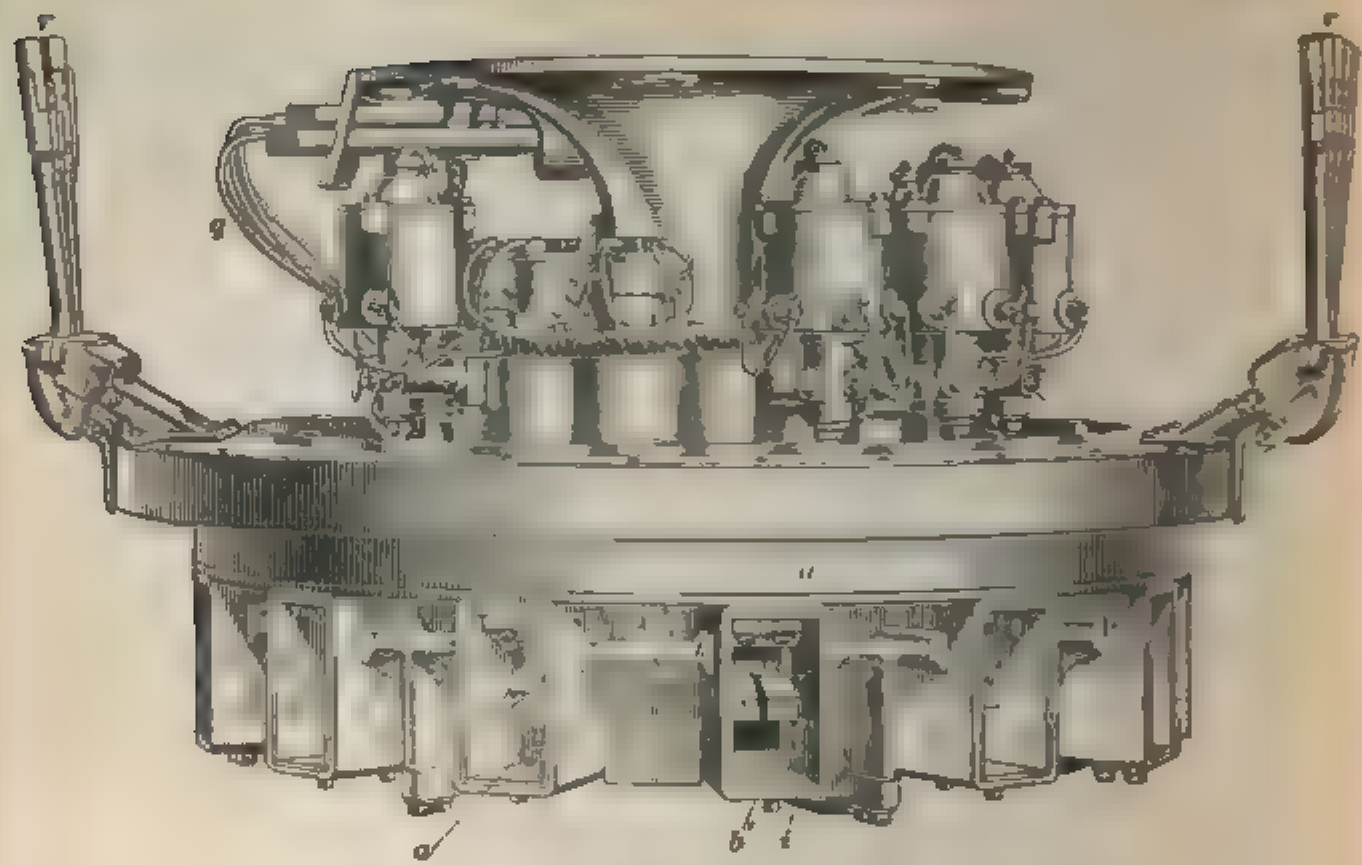


FIG 23

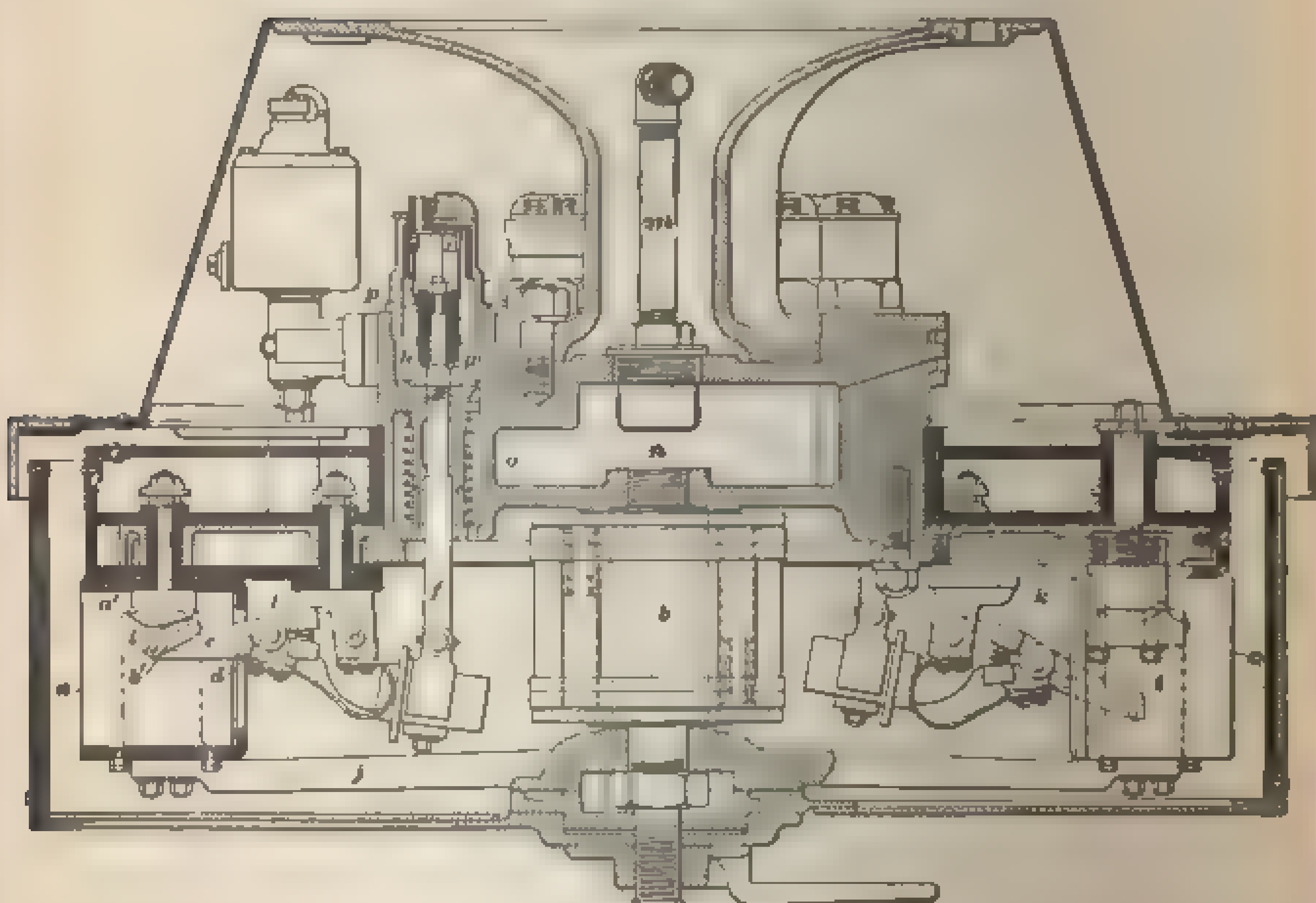


FIG 24

conjunction with the small compression spring *l* is to give contacts *a'*, *b'* a certain amount of wiping action that prevents sticking. The compressed air for operating the switches passes through pipe *m* into a central chamber, or reservoir, *n* of ample storage capacity to insure that ample pressure for operating the switches is always available. Admission of reservoir air to the operating cylinders of the switches is governed by electrically operated valves that are, in turn, dependent on the master controller for action. Each switch has a cylinder and operating coil above it, the coil being enclosed in a small iron case. The relative positions of the coil case, switch, and cylinder are shown in Fig. 24. Admission of air into cylinder *h*, Fig. 24, forces the piston down against the action of spring *o*, the object of which is to open the switch promptly on exhausting the air from the cylinder. Over certain of the operating cylinders, small switches *p*, called *interlocks*, are arranged to be operated by the movements of the piston within the cylinder; these interlocks are used in connection with certain automatic features better understood after considering Figs. 36 and 37, which are diagrams of connections. In Fig. 23, wires *q* carry the control current to the electromagnetic valves; the main current wires connect to terminals *r*, *r*.

### MASTER CONTROLLER

**36.** The standard **master controller** used for operating single cars, or trains equipped with the Westinghouse unit-switch system, is illustrated in Figs. 25 and 26, which show the device with the cover on and off, respectively. In Fig. 25, the operating handle *a* is in the off-position, corresponding to the off-position of cylinder *a'*, Fig. 26. The cylinder *a'* consists of a single metal spider mounted on a horizontal shaft *b*, the turning of which causes the cylinder to engage fingers *c*, *c*. The operating handle can be placed in position only when the controller cylinder is at the off-position, and to rotate the handle, pin *d* must be depressed, thus raising a small lever that interferes with lugs cast on the cover. A movement of the operating handle to the right, corresponds

to a forward motion of the car or train; and a movement to the left, reverses the motion. If the operating handle be moved to the position marked by lug *g*, circuit combinations will automatically change until the motors are in full series across the line; as long as the operating handle is kept in this position, the combinations will not change, but an advance to the position marked by lug *h*, will automatically change the combination until the motors are in parallel across the line. If the handle be released at any stage of its operation, spring *i*, Fig. 26, will return it to off-position, in which all circuits are automatically interrupted.

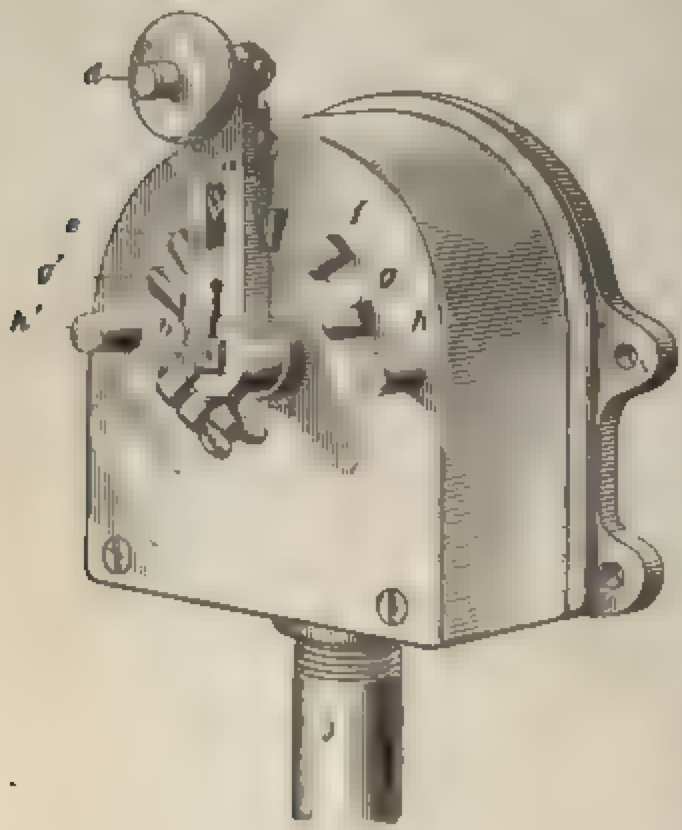


Fig. 25

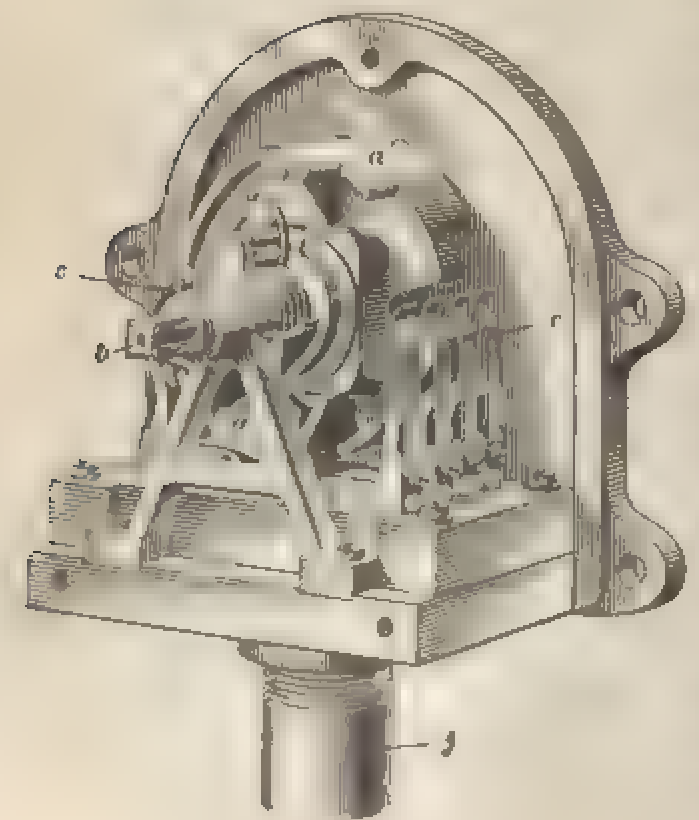


Fig. 26

The first stage of the movement of the handle from its off-position throws all reversing devices to a position corresponding to the direction in which it is desired to move the car or train, assuming that the reverser does not already occupy a position corresponding to the desired movement. It also

allows a flow of current through the motor circuit. This current, however, is too small to start the car, the maximum starting-coil resistance being in circuit. On the forward side of the master controller, the position on which these preliminary circuits are established is not indicated; on the reverse side, however, an additional lug *e*, Fig. 25, is provided. In emergency cases of reversal, it is well to pause on position *e*, for while the current flow on that position is insufficient to start a car it is sufficient to apply considerable braking action in reversal where the line E. M. F. and counter E. M. F. of the motors add together, and a pause there lessens the likelihood of tripping the line circuit-breaker. If the reversing devices are not in the proper position the motor circuit can take no current.

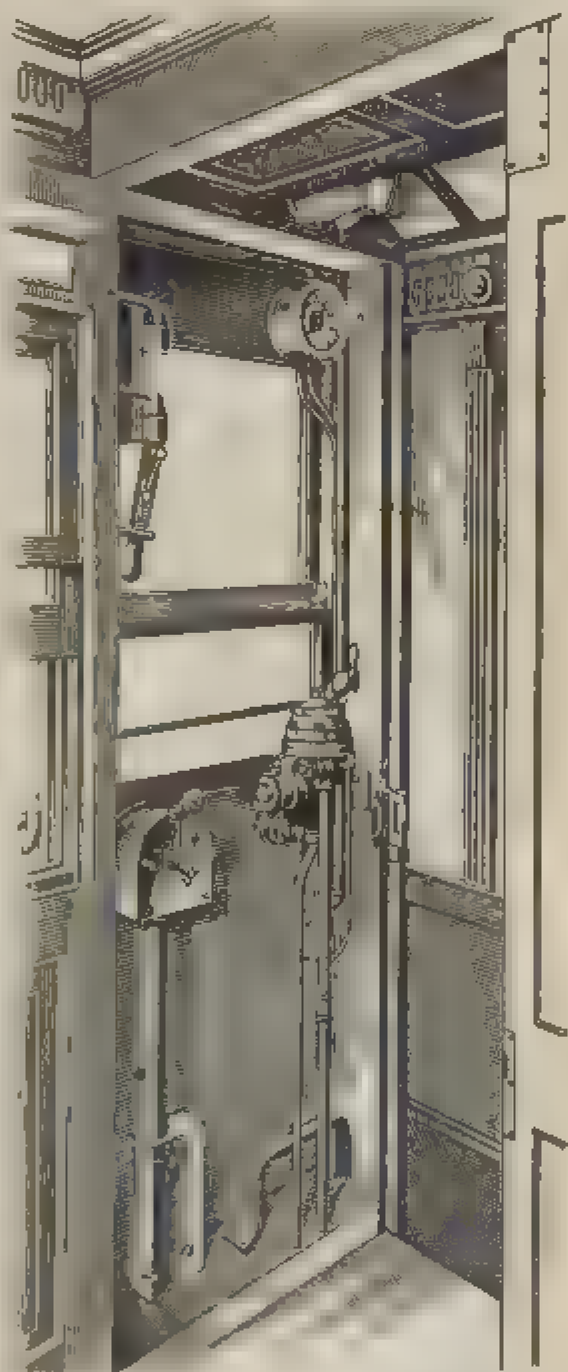


Fig 27

The control-circuit wires are introduced into the master controller through pipe *j*, which may also serve as a leg for steadying the device. As 16½ volts is the maximum pressure to which the control circuit is subjected, no difficult insulation problems are encountered and the use of a magnetic blow-out coil for extinguishing arcs in the controller is unnecessary. Fig. 27 shows the location of the master controller in the special compartment, on an elevated railway car, provided for the controller and air-brake operating devices.

## REVERSE SWITCH

**37.** A general view of the **reverse switch, or reverser,** used with the unit-switch system of control, is shown in Fig. 28. The function of the reverser is to interchange the main motor armature connections so as to reverse the direction of rotation of the armatures. In Fig. 28, *a* is the base and *b* the feet for securing the device to the under side of the car, *c, c* being the lugs to which the cover is attached. The construction and operation of the reverser are as follows: An insulating block *d* carries two sets of metal strips *e*, of which one set or the other, according to the position of block *d*, engages stationary fingers *f*. By means of compressed air admitted to cylinders *g* or *g'*, a reciprocating motion can be given to block *d*. Electromagnets *i, i'* operating valves *j, j'* immediately beneath them, determine which of the cylinders *g, g'* shall receive compressed air and thereby determine the position of block *d*. If the master controller has been moved to the forward position, electromagnet *i* will be energized and operate the valve that admits air to the cylinder, thus forcing block *d* and its contacts to a position where the train movement will be forward. Movement of the master controller

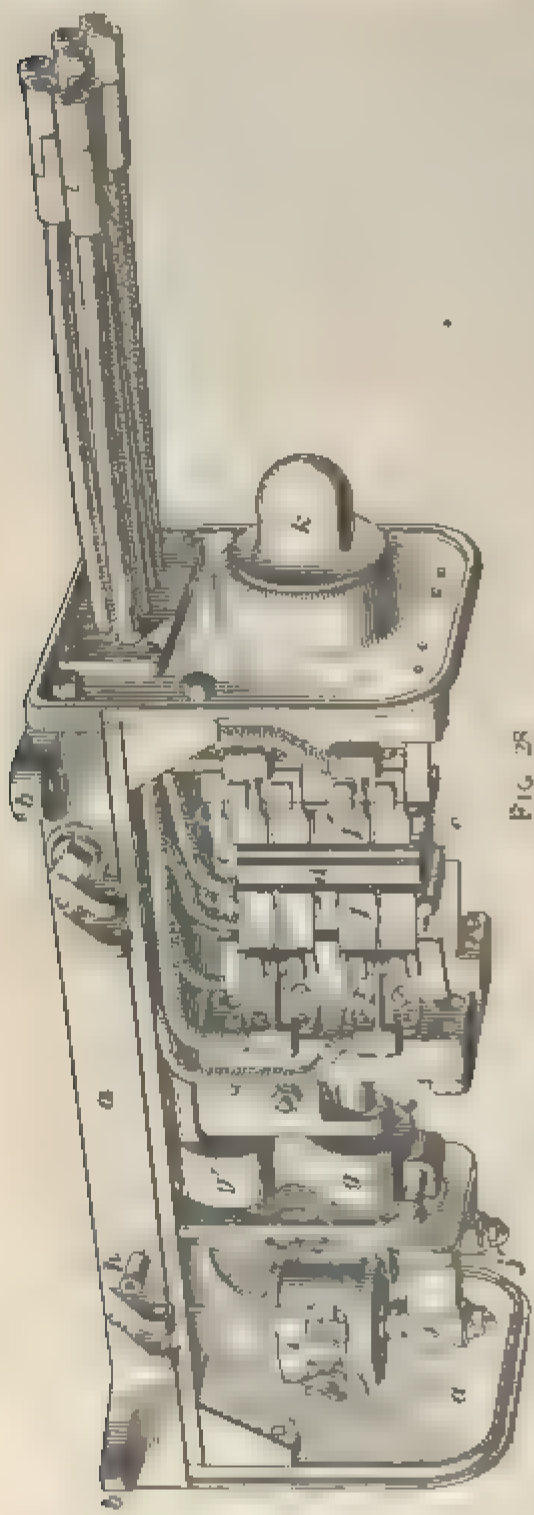


FIG. 28

to the reverse side of its off-position will energize electromagnet $i'$, thereby operating the reverser so as to give the car or train backward motion. The reverser has no off-position, and as it is never required to interrupt a circuit that is carrying current, it has no blow-out coil for extinguishing arcs at the contact fingers. Protected by cover $k$ is a small interlocking switch, the movable contact of which is attached to the reciprocating switch block; the contacts of this switch are indicated in Fig. 37. The function of the interlock is to insure that the switch group cannot operate unless the reverser has been fully thrown in the direction indicated by the master controller. The first circuit established when operating the master controller is one that insures that motor current cannot flow unless the reverser is in the correct position; this precludes the possibility of having different cars in the same train with their reversers in opposite directions.

### MOTOR CUT-OUT SWITCH

**38.** Figs. 29 and 30 illustrate the cut-out switch used when one or both motors have to be cut out of service. Stem $b$ passes through the car floor and terminates in a hand wheel by means of which the switch can be turned to any of four indicated positions, which are as follows: 1, both motors in circuit; 2, No. 1 motor in, No. 2 motor cut out; 3, No. 2 motor in, No. 1 motor cut out; 4, both motors cut out. In both figures, the motor wires enter the switch casing at $c$ and two

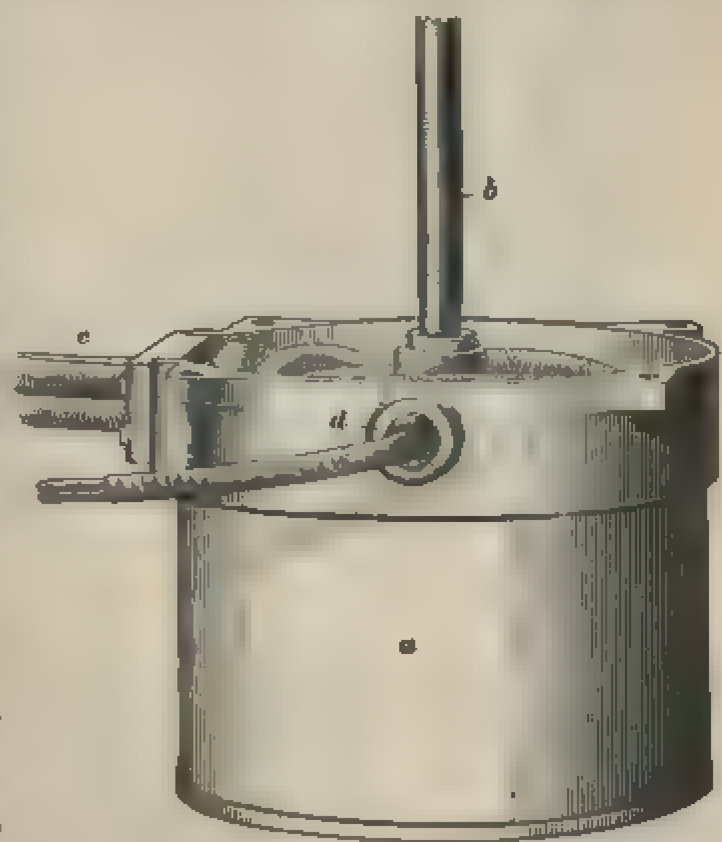


FIG. 29

control-circuit wires at *d*. In Fig. 30, *e* is one of ten contact segments mounted on a cylinder operated by stem *b*. The motor-current fingers are shown at *g* mounted on insulated studs *h* secured to the casing. Small fingers *i*, *i* constitute an interlock whereby the unit switches are unable to create any parallel motor combination except when both motors are cut in.

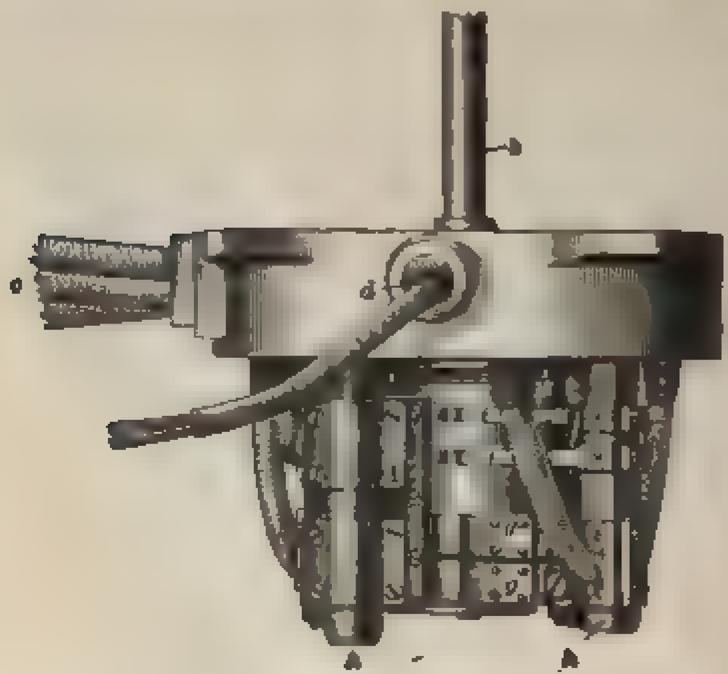


FIG. 30

**TRAIN-LINE COUPLER**

**39.** The control-circuit train cables of abutting cars are coupled by means of devices similar to those described in connection with the type M system of control, but as the unit-switch system employs but seven wires at a maximum difference of potential of 16 volts, the coupling devices are smaller than those required to handle the line voltage. Fig. 31 shows one of the flexible connections used between cars. Coupling heads, or plugs, *a* consist of a malleable-iron shell surrounding a cylindrical piece of insulating material in which are set seven

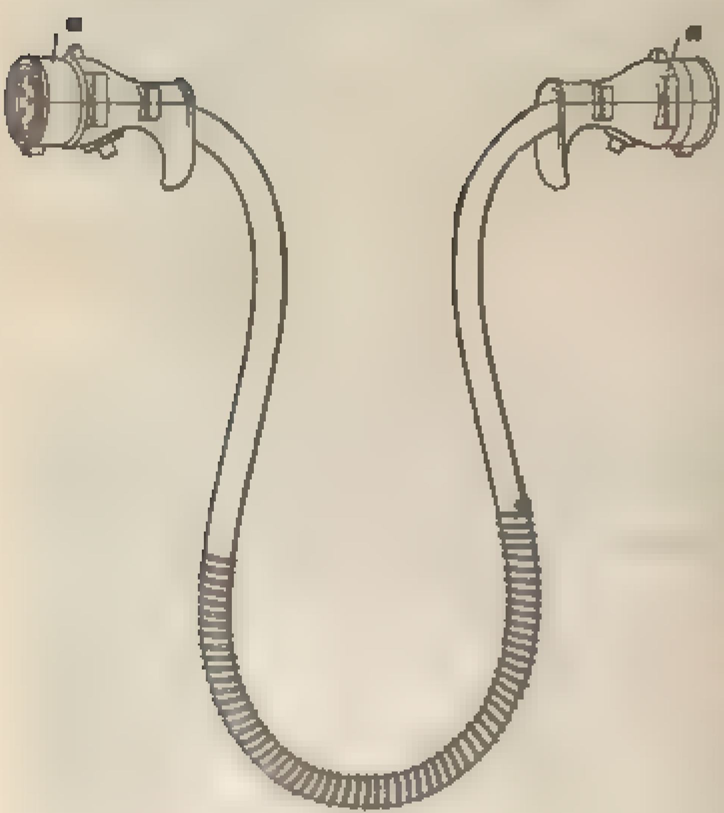


FIG. 31

small brass receptacles. Permanently mounted on the ends of all cars to be made up into trains are two sockets, each containing seven split pins mounted on an insulating base. Each split pin in a socket enters a corresponding receptacle in the plug, thereby connecting a certain control wire on one car to the same control wire on the abutting car and preserving the individuality of each wire throughout the length of the train.

### LIMIT SWITCH

**40.** Fig. 32 illustrates the **limit switch,** the object of which is to regulate the rate of acceleration by stopping the progressive action of the unit switches whenever the motor current exceeds a predetermined value. In Fig. 32, *a* is the operating coil of which *b* and *c* are motor-circuit terminals; *d* is an iron plunger carrying at its lower end a metal disk *e*,

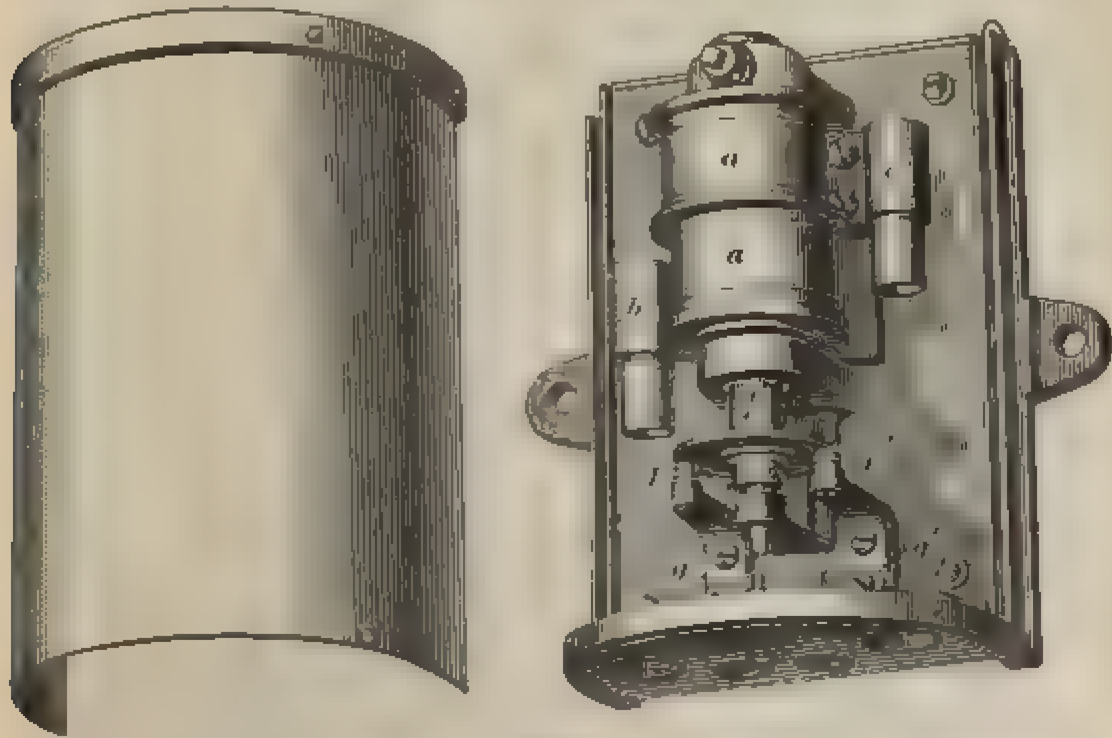


FIG. 32

which normally rests on contact points *f*, *f'* that connect to control-circuit terminals *g*, *g'*, respectively. The operating coil of the limit switch is connected in series with the negative side of the No. 1 motor field and the switch device composed of disk *e*, contacts *f*, *f'*, and terminals *g*, *g'*, is connected in series with the *L* branch of the No. *4* wire (see

wiring diagram, Fig. 37), which is the positive battery connection for the pick-up coils of all unit-switch magnets except *5*, *6*, *7*, and *8*. The limit switch can be adjusted to open at any predetermined motor current and the opening of the switch opens the circuit leading to the pick-up coils of all unit switches except those stated, and these switches will not be closed until a decrease in the motor current allows disk *e* to drop and close the limit-switch contacts. To illustrate, suppose the No. *9* switch, Fig. 37, to close, and the motor current on that notch to be 250 amperes, the value at which the limit switch is set to operate being 240 amperes. The limit switch will operate immediately and arrest any further progressive action of unit switches, but will not cause those unit switches already closed to open. The limit switch is distinctly an acceleration regulator, making the rate of acceleration largely automatic and preventing excessive current consumption and wheel slippage due to careless handling of the controller.

LINE SWITCH

**41.** Figs. 33 and 34 are, respectively, a front view, back view, and interior view of the **line switch**, which is essentially

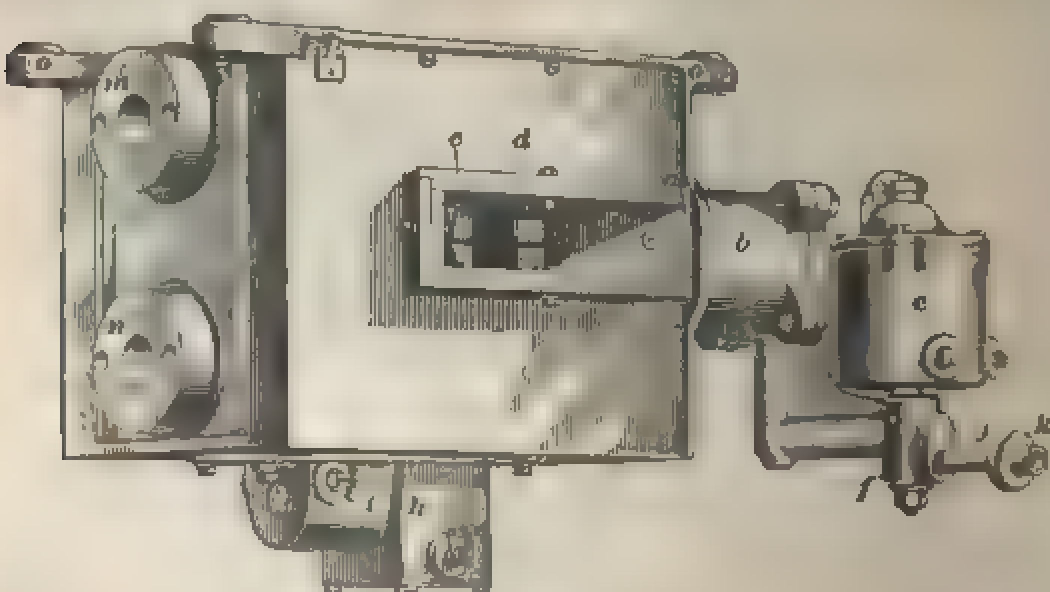


FIG. 33

an automatic circuit-breaker, and Fig. 35 is a view with the cover removed. Corresponding parts are marked the same

in the three views and their connections will be understood by referring to Fig. 37. In Fig. 35, *a a* is the blow-out coil, which also serves as a tripping coil, wound in two sections and composed of copper strip coiled on edge; *b* is the air

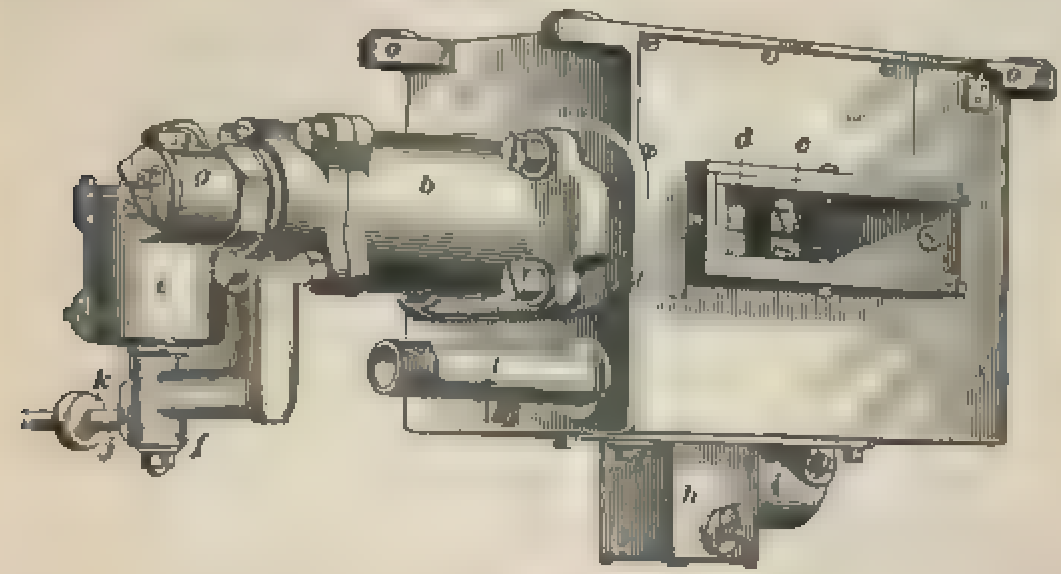



FIG. 34

cylinder in which a piston moves back and forth, thus separating contacts *c*, *d* or bringing them together, as the case may be, and thereby opening or closing the main motor

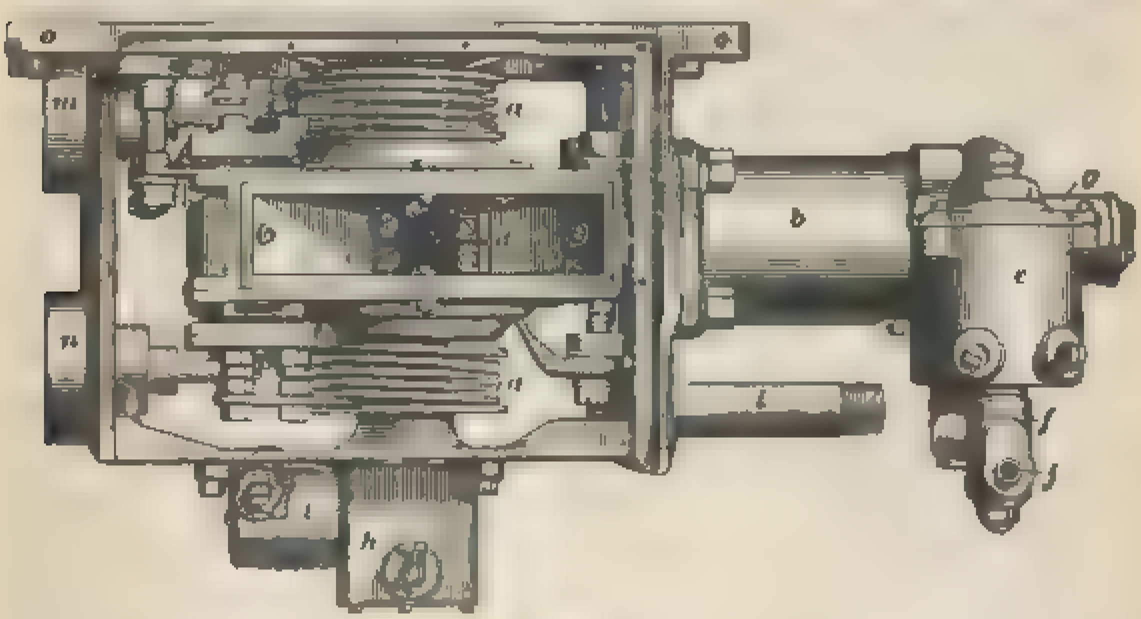



FIG. 35

circuit. Magnet coil *e* controls the position of enclosed valve *f* through which air is admitted to cylinder *b*, and an interlock switch is enclosed in *g*. The circuit-breaker tripping device is shown at *h*, and the resetting device at *i*. Operating

air enters through pipe *j*, which includes an insulation coupling *k*, Fig. 33, to prevent grounding the line-switch casing through the piping system. The control wires enter and leave through pipe *l*, and the motor-circuit wires through wooden bushings *m* and *n*. Motor current entering the breaker passes successively through top blow-out coil section, contacts *c* and *d*, and bottom blow-out coil section. The lugs for supporting the device from the under side of the car are shown at *o*.

**42.** The line switch, or circuit-breaker, is connected between the trolley and the unit-switch group, as indicated in Fig. 37. When the trip is opened, it is held open by a catch that can be withdrawn either by hand operation or by momentarily closing the circuit through the reset coil by closing the circuit-breaker reset switch located alongside the master controller. This can be done only when the master controller is at off-position. The armature of the overload trip works against a spring, which can be adjusted for different values of the tripping current. The object of the line-switch interlock, which is closed only when the line switch is open, is to short-circuit the contacts of the line relay and thereby permit operation of the switch group for testing purposes, without the possibility of establishing any main circuits that can allow current to flow. The line switch is not always used, and in the equipment shown in Fig. 21, it is not indicated.

## LINE RELAY

**43.** The function of the **line relay,** the connections of which are indicated diagrammatically in the lower right-hand corner of Fig. 37, is to open all the switches except the line switch when there is no power on the line. One terminal of the relay-operating coil is connected through a resistance to the inside of the line switch and the other terminal to the ground. The relay contact marked 8 is connected to one contact of the overload trip switch, to $B-$ side of the line switch magnet coil, and one contact of the line-switch interlock. The other relay contact *S* connects to the opposite side of

the line-switch interlock and also to one contact of the No. *6* unit-switch interlock. The result of these connections is to make the line-relay switch the return battery wire for all switch coils except that of the line switch. The line-relay switch is normally held open by gravity, but closing the line switch, of which the operating coil does not depend on the line-relay switch for its battery return, provides a trolley connection from which current flows through the line-relay operating coil. This current closes the line-relay switch, which remains closed as long as the line switch is closed, the latter being open only when the master controller is at off-position or when the overload trip switch operates.

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### RESISTANCE COIL

**44.** The resistance employed with the unit-switch control equipment is of the Westinghouse grid type, and is made up of eleven units, the connections of which are indicated in Fig. 37. The grids are grouped to form seven resistance sections, and in parallel with each section is a corresponding unit switch, the closing of which short-circuits the section.

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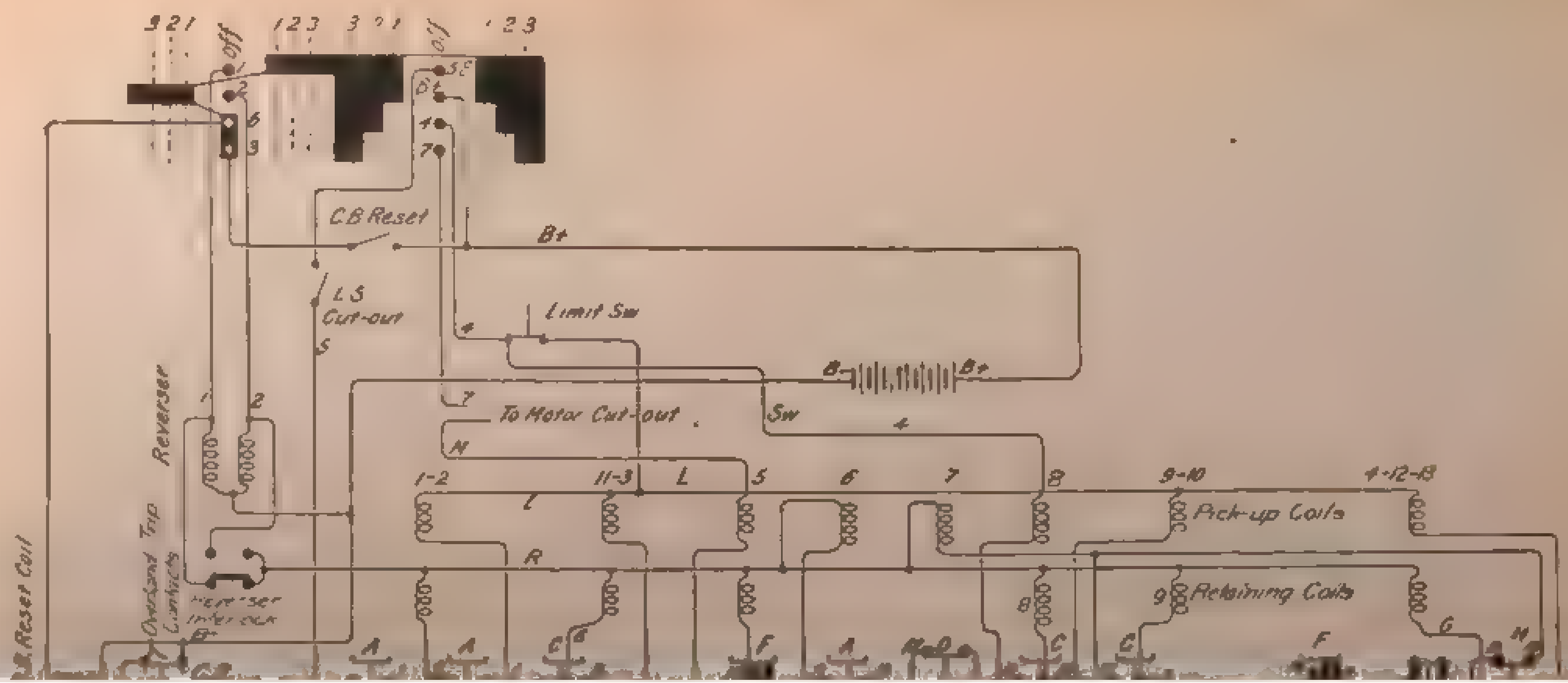
### CONNECTIONS AND OPERATION

**45.** The connections of the control or operating circuit for a single car are shown in Fig. 36, the wiring being simplified somewhat in order to make the circuits easier to follow. For example, a single set of cells connected directly to the controller is shown for supplying the control current, while in an actual installation two sets of cells are used, as shown in Fig. 37, and are connected to switches so that one set can be charged while the other is in use. Also, the seven control wires pass from end to end of the car, as indicated in Fig. 37, and terminate in sockets. In Fig. 36, the wiring is shown as applying to a single car, but in following out the operations it should be remembered that the movement of the master controller on the front car, or any other car of a train, operates the main controllers on all the



C.B Reset
B+
L S Cut-out
Limit Sw
To Motor Cut-out
Sw
Reverser
Pick-up Coils
Retaining Coils
Overload Trip Contacts
Reverser Interlock
Reset Coil

motor cars because the control circuits pass from car to car and are energized throughout the train. The unit switches, without main current connections, are shown numbered in the lower part of the figure. The small switches shown above the unit switches *1*, *2*, *4*, *5*, *6*, *7*, *8*, *9*, *11*, *12*, and *13* represent the interlocks. Where the cross-piece of these small switches is shown a short distance above the terminals of the switch it indicates that the interlock is open when the corresponding main switch is open, and that when the piston of the main switch goes down the interlock closes. When the cross-piece is shown below, but in contact with the terminals, it indicates that the interlock opens when the piston goes down and the main switch closes.

In Fig. 36, the interlocks on unit switches *1*, *2*, *6*, *8*, *9*, and *11* are open and those on unit switches *7* and *12* are closed, the unit switches themselves being all open. The construction of the interlocks on unit switches *4* and *5* is different from that of the others. The curved cross-piece, represented as touching the two right-hand long strips, slides up and down with the piston. Soon after the piston starts its downward movement, the third strip from the right makes contact with the sliding cross-piece; just before the piston reaches the end of its downward stroke, the sliding contact engages the left-hand short strip, but leaves the extreme right-hand strip marked *12* on the interlock of switch *5*, and *11* on that of switch *4*. Certain of the unit switches are provided with two coils, one of which is a pick-up coil for operating the switch and the other a retaining, or holding, coil for holding the switch closed even though current be cut off from the operating coil. The object of the retaining coils will be better understood after the operation on the various controller notches has been considered, but, briefly, their function is to hold such switches, as may have already operated, closed even though the limit switch, because of excessive current, opens and thus prevents any other unit switches from closing. That is, the holding coils prevent all the switches from opening and thus making it necessary to cut out the resistance again from the beginning.

**46. Operation on First Position.**—Movement of the master switch handle to its first forward position establishes connections as follows: Master controller finger *B*+, connected to the positive battery terminal, connects to fingers *5 S* and *1* through the master controller cylinder. Finger *5 S* introduces current through the magnet coil of the line switch, assuming the line switch cut-out to be closed, reaching the negative battery wire by way of the overload trip contacts, and excitation of this circuit closes the line switch by admitting air to its operating cylinder. The closing of the line switch provides, at *T*, a trolley connection and allows current to flow through the lifting coil of the line relay to ground, thereby closing the line-relay switch, the contacts of which are in parallel with the line-switch interlock. A small rheostat is connected in series with the line-relay coil to limit the current. Simultaneously a current from finger *1* passes through reverser coil *1* and thence to the negative side of the battery. This current opens the valve controlled by reverser coil *1*, and if the reverser is not already in the forward position, it will promptly move to it. As soon as the reverser throws the full length of its travel, the safety switch on the end establishes connection between the positive battery wire *B*+ and wire *R*, which represents the positive sides of the retaining coils Nos. *1–2*, *11–3*, *5*, *8*, *9–10*, *4–12–13*, and the pick-up coils Nos. *6* and *7*.

The reverser must be fully thrown forward or back, otherwise its safety switch will not connect wire *R* to battery. Assuming the reverser to be at the extreme end of its travel, wire *R* will become *B*+ and current passes through the No. *6* magnet coil, to *B*−, by way of the closed line-relay switch, thereby operating the No. *6* unit switch and closing its interlock *S–A–13*. The closing of this interlock causes current to take path *R*–No. *7* magnet coil–contacts *19*, *12* of unit switch *13*–contacts *12*, *11* of interlock *5*–contacts *11*, *13* of interlock *4*–contacts *13*, *A*, *S* of interlock *6*, here joining with the current from the No. *6* magnet coil and flowing with it through the line-relay switch to *B* and thereby operating unit switch *7* also. The motors are now in series

with resistance, as will be seen by tracing out the main current path in Fig. 37, assuming the line switch and unit switches *6* and *7* to be closed.

**47. Operation on Second Position.**—On moving the master controller to the second position, thereby connecting master controller finger *4* to $B+$, current flows out on the No. *4* wire, through the magnet coil of switch *8*, which immediately operates, through interlocks of switches *5*, *4*, and *6* to join in with the operating currents of switches *6* and *7*, and through the line relay switch to $B-$. Through the limit switch, a branch of the No. *4* wire connects to the $L$ wire, which is the positive side of the pick-up coils of magnets *9–10*, *11–3*, *1–2*, and *4–12–13*. The closing of No. *8* interlock due to the operation of No. *8* unit switch, has given a $B-$ connection to the No. *8* retaining coil and also to the No. *9–10* pick-up coil, which closes switches *9* and *10*. The closing of switch *9* gives its retaining coil a $B-$ connection through its own interlock and interlocks of switches *8*, *5*, *4*, and *6*. The operation of unit switch *9* also gives a $B-$ connection to pick-up coil *11–3*, which immediately picks up unit switches *11* and *3*, which are retained by their retaining coil, which gets its $B-$ connection through interlocks *11*, *9*, *8*, *5*, *4*, and *6*. The closing of unit switch No. *11* closes its interlock through which a $B-$ connection is given to the pick-up coil of No. *1–2* magnet, which picks up switches Nos. *1* and *2*, which are then retained by their retaining coil, getting a $B-$ connection through interlocks of switches *2*, *11*, *9*, *8*, *5*, *4*, and *6*. The motors are now in full series across the line.

**48. Operation on Third Position.**—On moving the master switch to the third position, finger $B+$ is connected to the No. *7* wire and battery current takes path *7*–motor cut-out switch–interlock wire *M*–pick-up coil *5*–interlocks of switches *1*, *13*, *5*, *4*, *6*–$B-$, by way of the line relay, as in preceding cases. The closing of No. *5* switch first completes the circuit of its own retaining coil through contacts *10* and *11* on No. *5* interlock, contacts *13* and *11* on No. *4* interlock, No. *6* interlock to $B-$, as usual; toward the end

of the piston stroke, the sliding contact on interlock No. *5* breaks connection with contact No. *12*, thereby depriving the pick-up and retaining coils *7*, *8*, *9–10*, *11–3*, and *1–2* of their *B*– connections and opening these switches. When No. *5* switch is fully closed, the short contact of its interlock completes the circuit through the pick-up coil *4–12–13* as follows: *B*+ –*4*–pick-up coil *4-12-13*–interlock on switch *7*–interlock on switch *12*–interlock on *5*–interlock on *4*–interlock on *6*–line relay–*B*–. Switches *4*, *12*, and *13* do not close until switch *7* has fully opened, because interlock *7* is part of the circuit through pick-up coil *4–12–13*, and this interlock is closed only when its unit switch is entirely open. When switch No. *13* closes, its lower interlock contacts establish a *B*– connection to the retaining coil through interlocks *13–7–4* and *6*. In the first part of the downward movement of the piston of switch No. *4*, its interlock engages the low contact, thereby establishing another *B*– path, the first path having been broken in two places by operation of unit switches *4* and *12*. This is done when switches *4* and *12* are nearly closed and the *B*– connection of the pick-up and retaining coils of switch No. *5* is broken; this switch then opens. The motors are now in parallel and have resistance in series. The full closing of switch No. *4* connects the short contact of its interlock to *B*–, thereby providing a *B*– connection for the pick-up coil of the *9–10* magnet, which picks up switches *9* and *10*. The closing of switch No. *9* causes the consecutive closing of *11–3* and *1–2*, as on the second position. The motors are now in full parallel and will remain so until the master controller is moved to off-position.

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### CAR-WIRING DIAGRAM FOR UNIT-SWITCH CONTROL

**49.** Fig. 37 is a car-wiring diagram of the unit-switch system and shows the main motor connections that are omitted in Fig. 36. In Fig. 37, the normal condition of a unit-switch equipment with a train at a standstill, is as follows: The master controllers are both at off-position; all unit switches, the line switch, the line-switch cut-out and

circuit-breaker resetting switches (see small switches near master controllers) are open. One battery of storage cells is ready for use and the other is charging through the lamp circuit. The reverser is either in forward or reverse position and the motor cut-out switch is on the first position in which both motors are cut in. The line relay switch is open and the limit switch closed.

**50.** A motorman on taking a car, first closes the pump switch and raises the air pressure to a standard value. The line-switch cut-out is then closed and the resetting switch closed for an instant to insure that the circuit-breaker trip may be at the upper end of its stroke where it provides return battery connection *B*— not only for the magnet coil of the line switch but also for the several control-circuit arrangements.

The circuit-breaker resetting coil is operative only when the master switch is at off-position, because only in this position are master-switch fingers *6* and *3*, which are part of the resetting circuit, connected. With the circuit-breaking trip of the line switch closed, one of the first effects of advancing the master controller to the first position is to energize the line-switch magnet coil, thereby admitting air to the line-switch operating cylinder, closing the main circuit-breaker contacts, and opening the line-switch interlock. The immediate effect of closing the line-switch main contacts, is to send current through the magnet coil of the line relay and thereby close the line-relay switch. It must be remembered that the line-relay switch handles battery current, but its magnet coil is energized by line current. The closing of the line-relay switch provides the *B*— return for the various control circuits connecting to the No. *6* interlock, as considered in connection with Fig. 36. As line voltage is necessary to keep the relay switch closed, the relay switch will open all automatic switch circuits, except that of the line switch, if the power leaves the line or the trip coil of the line switch operates. While closing the line switch renders the *C T* wire, extending from the line switch to the unit switch No. *12*,

alive, no motor current can flow until flow of current through the reverser circuit throws the reverser and establishes the safety switch $B+R$ connection that operates unit switch *6*, the operation of which sets off *7*. Moving the master controller to the series running notch, automatically works the motor up to full series; and movement to the multiple notch, automatically changes the motors from full series to parallel with resistance in series, then to full parallel. Should the master controller be advanced too rapidly, the limit switch will operate in the manner already described, and will prevent any further cutting out of resistance until the current has dropped to normal value. However, the opening of the limit switch does not interfere with the current in the holding coils and the switches that have operated up to this point do not drop and cut resistance back in. By means of the various interlocks and the connections between operating coils, the cutting out of resistance is performed automatically after the controller has been placed on notch *2* or *3* and does not require a movement of the controller for each section of resistance cut out, as with the type M system.

# INDEX

NOTE.—All items in this index refer first to the section and then to the page of the section. Thus, "Boosters 36 17" means that boosters will be found on page 17 of section 36.

## C

## G

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## T

c c-r